CLEAN WATER **WATER POLLUTION CONTROL RESEARCH SERIES ● ORD-4**

PB188511

W 70-02392

Combined Sewer Separation Using Pressure Sewers

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

212

U.S. DEPARTMENT OF THE INTERIOR ● FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Reports describe the results and progress in the control and abatement of pollution of our Nation's Waters. They provide a central source of information on the research, development and demonstration activities of the Federal Water Pollution Control Administration, Department of the Interior, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Triplicate tear-out abstract cards are placed inside the back cover to facilitate information retrieval. Space is provided on the card for the user's accession number and for additional keywords. The abstracts utilize the WRSIC system.

Water Pollution Control Research Reports will be distributed to requesters as supplies permit. Requests should be sent to the Publications Office, Department of the Interior, Federal Water Pollution Control Administration, Washington, D.C. 20242.

Previously issued reports on the Storm & Combined Sewer Pollution Control Program:

WP-20-11	Problems of Combined Sewer Facilities and Overflows-1967.
WP-20-15	Water Pollution Aspects of Urban Runoff.
WP-20-16	Strainer/Filter Treatment of Combined Sewer Overflows.
WP-20-17	Dissolved-Air Flotation Treatment of Combined Sewer Overflows.
WP-20-18	Improved Sealants for Infiltration Control.
WP-20-21	Selected Urban Storm Water Runoff Abstracts.
WP-20-22	Polymers for Sewer Flow Control.

BLANK PAGE

Combined Sewer Separation Using Pressure Sewers

Feasibility and Development of a New Method
for Separating Wastewater from
Combined Sewer Systems

Federal Water Pollution Control Administration, Department of the Interior

by

American Society of Civil Engineers
345 E. 47th. Street
New York, N.Y. 10017

Program No. 11020 EKO
Contract No. 14-12-29

October, 1969

FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

This report is concerned with the separation of community wastewaters and runoff from rainfall and snowmelt in areas presently served by combined and intercepting sewers. Separation is accomplished by withdrawing the wastewater fraction of flows from existing plumbing systems and passing it through a sequence of added systems components as follows: (1) a storage, grinding and pumping unit within each building; (2) pressure tubing fished from the unit through each existing building sewer into the existing combined sewer; and (3) pressure piping inserted in that sewer and extending to the existing intercepting sewers that carry the wastewaters to treatment and disposal works. Runoff from rainfall and snowmelt, thus unencumbered by wastewaters, is removed from the community through the residual passageways of the one-time combined sewer system, which has thus become a combination of a new pressure conduit system within an old gravity conduit system.

The feasibility of this scheme of separation, the selection of available systems components and the development of required new systems components are described in this report on the basis of information drawn from 25 project reports and technical memoranda.

The feasibility of storing, grinding and pumping sewage from individual residences has been established; and standard comminuting and pumping equipment will be satisfactory for serving larger buildings. Acceptable types of pressure tubing are available that can be pushed and pulled through existing building drains and sewers. Pressure conduits can be suspended inside combined sewers that can be entered by workmen. There are combined sewer areas that can be separated most effectively by a version of the method investigated, but generally pressure systems will cost more than new gravity systems. New capabilities developed appear to be of potentially greater use for applications other than separation, such as new construction including utility corridors, and introduce viable alternatives for design of wastewater sewerage.

This report was submitted in fulfillment of Contract Number 14-12-29 between the Federal Water Pollution Control Administration and the American Society of Civil Engineers.

CONTENTS

Section | Title | Page

ABSTRACT iii

LIST OF TABLES viii

LIST OF FIGURES x

I SUMMARY, FINDINGS AND CONCLUSIONS

Summary 1
Findings and Conclusions 3

II INTRODUCTION

What Is Combined Sewerage? 8
Extent of Combined Sewerage in the United States . . 11
The Proposed Project of Study 12
Authorization, Scope and Content of the Report . . . 15
Opinion Survey 16

III ALTERNATIVE METHODS OF REDUCING POLLUTION FROM COMBINED SEWER OVERFLOWS

Introduction 19
Complete Separation of Existing Combined Systems . . 19
Partial Separation of Existing Combined Systems . . 20
Retardation or Storage of Interceptor Overflows . . 21
Treatment of Overflowing Waters 21
Other Alternatives for Reducing Pollution by Overflows 22
ASCE Combined Sewer Separation Project 23

IV RESIDENTIAL AND COMMERCIAL SEWAGE FLOWS

Introduction 27
Information from Earlier Studies 27
Project Studies 28
Results of Project Studies 28
Flow Rates in Collection System 33
Comparison of Per Capita Flows with Flows Based on Water Demand Ratios 35
Design Curves 37
Flows from Commercial Buildings 37
Comparison of Observed Sewage Discharges with Water Demands 42
Unit Fixture Discharge Rates 44
Storage Volume and Minimum Required Pump Rate . . . 47
Suggested Measurements 47

CONTENTS (Continued)

Section Title Page

V EQUIPMENT FOR STORING, GRINDING AND PUMPING SEWAGE FROM RESIDENTIAL AND OTHER SMALL SOURCES

Introduction 50
Performance Requirements 50
The General Electric Household SGP Unit 51
Equipment Installation and Operating Costs 51
Alternative Equipment 59

VI CONVENTIONAL EQUIPMENT AND CONTROLS FOR STORING, COMMINUTING, AND PUMPING SEWAGE FROM COMMERCIAL BUILDINGS AND OTHER LARGE SOURCES

Introduction 60
Comminuting and Pumping Equipment 60
Combined Grinders and Pumps 61
Non-Clog Centrifugal Pumps 61
Pneumatic Ejectors 61
Cost of Comminutor-Pump Installations 63

VII PRESSURE SEWER SYSTEMS

Introduction 64
Tubing and Conduit Defined 64
Materials 65
Insertion of Tubing 65
Tubing and Conduit Installation 65
Ranges of Combined Sewer Sizes 71
Suspension of Conduits within Existing Sewers . . . 72
Burial of Tubing and Conduit by Plowing 72
Other Installation and Maintenance Considerations . 73
Pressurized Sewerage Collection System Layouts . . . 73
Conduit Sizing 82
System Hydraulics and Controls 84

VIII INSTALLATION OF THE PROJECT SCHEME IN EXISTING SEWERS

Introduction 90
Relative Cost and Reliability of Pressure System . . 90
Effect of Inserted Pipes on Hydraulic Capacity of Sewers 90
Maintenance and Operation of Pressure System 94

CONTENTS (Continued)

Section | Title | Page

IX INTRODUCING PRESSURE SEWER SYSTEMS INTO EXISTING COMBINED SEWER DISTRICTS

Introduction 96
Study Areas 97
Separation of Building Plumbing 97
San Francisco 97
Milwaukee 107
Boston 107
Summary of Plumbing Separation Studies 110
Storage-Grinder-Pump Units 110
Building Service Connections 113
Pressure Sewer Systems 113
Sewage Flow Rates 113
Conduit Materials 114
Hydraulic Criteria 114
Service Districts and Pressure Zones 114
Alternative Arrangements of Collection Systems . . . 114
Layout Studies 115
San Francisco 115
Milwaukee 119
Boston 124
Estimates of Annual Costs, Milwaukee Study Area . . 124
Summary and Comparison of Estimated Costs, Three Study Areas 129
Evaluations and Conclusions of Engineering Consultants 132

X BROADER ASPECTS OF PLUMBING SEPARATION

Introduction 136
Summary 136

XI NON-TECHNICAL CONSIDERATIONS RELATED TO PRESSURE SEWER SYSTEMS

Introduction 142
Public Acceptance and Financial Support 143
Direct Precedents 143
Sampling Public Attitudes 144

XII BENEFITS AND DISADVANTAGES OF THE ASCE PROJECT SCHEME

Adjunct Applications 147

CONTENTS (Continued)

Section Title Page

XIII APPLICATION OF ASCE PRESSURIZED SEWERAGE SCHEME TO DISPOSAL OF SOLID WASTES FROM HOUSEHOLDS AND INDUSTRY

Introduction 151
Solid Wastes to Be Considered 151
Carrying Capacity of Sewers and Loads of Refuse Solids to Be Transported 152
Separation and Grinding of Solid Wastes 153
Treatment of Combined Solid Wastes 154
Costs and Benefits of Collecting and Treating Solid Wastes with Sewage 154
Conclusion 157

XIV FOLLOW-ON FIELD TESTING

Introduction 158
Field Testing of Household Units 158
Field Demonstration in an Entire Service District . 161

XV ACKNOWLEDGEMENTS 164

XVI BIBLIOGRAPHY 169

XVII PATENT NO. 3,366,339 178

XVIII GLOSSARY 182

APPENDICES

A ABSTRACTS OF PROJECT TECHNICAL MEMORANDA 186

B ABSTRACTS OF PROJECT SUBCONTRACTORS' REPORTS 193

TABLES

Table	Title	Page
1	Ratios of Household Water Demand Rates for Various Periods to Mean Daily Household Water Demand Rates . . .	31
2	Winter Water Demand	36
3	Northeastern U.S. Variations in Domestic Water Demand .	38
4	California Variations in Domestic Water Demand	39
5	Determination of Storage, for Synthetic Hydrographs, Pump Discharge Rate of 13 gpm	46
6	Mean Rates of Discharge of Individual Fixtures and Synthetic "Minimum" Discharge Rates for Fixture Combinations	48
7	Synthesized Storage-Pump Combinations	48
8	Specifications for Prototype Storage-Grinder-Pump Unit .	58
9	Tubing Less than 2 Inches in Diameter Considered for Pressure Building Connections	66
10	Pipe Materials 1½ Inches through 16 Inches in Diameter Considered for Pressure Conduits	67
11	Results and Observations of Pushing Tests	68
12	Results and Observations of Pulling Tests	69
13	Summary of Conduit Layout Characteristics	75
14	Characteristics of Study Areas	98
15	Summary — Building Plumbing Separation	112
16	Annual Cost of Sewer Separation, Prospect Avenue Study Area, Milwaukee, Wisconsin	128
17	Comparison of Annual Costs for Milwaukee Study Area . .	130
18	Estimates of Capital Cost	131

TABLES (Continued)

Table	Title	Page
19	Summary of Information on Costs of Building Plumbing Separation	140
20	Attitudes of Occupants of Twenty-Five Buildings to Experience with Pumping Units, Radcliff, Kentucky	145
21	Evaluation of ASCE Combined Sewer Separation Project Scheme	148
22	Typical Quantities of Community Refuse and of Sewage Solids	152

FIGURES

Number	Title	Page
1	Diagrammatic Example of Normal Functioning of Typical Combined Sewer System under Dry-Weather and Storm Flow Conditions	10
2	Pressure Sewerage Research Plan for ASCE Combined Sewer Separation Project	14
3	Variation in Daily Water Use	29
4	Variation in Peak Hour Water Use	30
5	Variation in Peak Hour Water Use, Combination of Sources	32
6	Mass Curve of Water Usage, Single Home	34
7	Water Demand Variations, Northeastern U.S.	40
8	Water Demand Variations, California	41
9	Relation of Extreme Discharges on Maximum and Minimum Days to the Average Daily Discharge of Domestic Sewage .	43
10	Comparison of Discharge from First Part of Test # 8, Station A, with Composite Discharge Curve	45
11	Storage-Pump Combinations to Accommodate Synthetic Inflows	49
12	Cut-Away Sketch of Household Storage-Grinder-Pump Unit .	52
13	Completed Prototype of Household Storage-Grinder-Pump Unit	53
14	Grinder Mechanism Viewed from Below through Pump Suction Bell	54
15	Close-Up View of Components above Mounting Flange . . .	55
16	Characteristic Curves, Prototype SGP Unit	56
17	Tanks for SGP Prototype	57
18	Effect of Comminutor and Garbage Grinder on Sewage Particle Sizes	62

FIGURES (Continued)

Number	Title	Page
19	Alternative Methods of Installing and Connecting Pressure Tubing and Conduit (One Side of Street, only, Shown)	70
20	Layout A	76
21	Layout A, Details for Fig. 20 Sector	77
22	Layout A, Arrangement for Manhole "W" in Figure 21 . . .	78
23	Example of Layout B	80
24	Layouts C, D and E	81
25	National Sanitation Foundation Pressure Sewer Layout . .	83
26	Example of Minimum and Maximum Hydraulic Grade Lines . .	86
27	Example of Pressure Zone Control	87
28	Example of In-Line Pumping	88
29	Turbulent-Flow Friction Factor for Concentric Annulus as a Function of Diameter Ratio	92
30	Deviation of Friction Factors for Conduits of Annular Cross-Section Based on Hydraulic Radius Concept	93
31	Location of Laguna Street Study Area, San Francisco . .	99
32	Basic Land Uses in the San Francisco Study Area	100
33	Location Map Milwaukee Study Area	101
34	Present Population, Present and Future Estimated Flow and Number of Dwelling Units	102
35	Location of Summer Street Sewer Separation Area, Boston, Mass., and Typical Building Selected for Study	103
36	Summer Street Sewer Separation Study Area, Boston, Mass.	104

FIGURES (Continued)

Number	Title	Page
37	Typical In-House Wastewater and Rainwater Plumbing Systems, San Francisco Study Area	105
38	Piping Requirements and Estimated Costs for In-House Separation of Selected Structures, San Francisco Study Area	106
39	Downspout Connection Groups Milwaukee Study Area	108
40	Plan of Basement Plumbing in 55 Summer Street	109
41	Section of Proposed Pit and Plumbing, Pressure System . .	111
42	Pressure Sewer System Layout — Alternative A, San Francisco Study Area	116
43	Details of Trunk System — Alternative A, San Francisco Study Area	117
44	Profile of Pressure Sewer System — Alternative A, San Francisco Study Area	118
45	Gravity Sewer System Layout, San Francisco Study Area .	120
46	Hypothetical Pressure Sewer System Layout M-1, Milwaukee Study Area	121
47	Hypothetical Pressure Sewer System Layout M-2, Milwaukee Study Area	122
48	Gravity Sewer System Layout M-Gr, Milwaukee Study Area .	123
49	Pressure Sewer System Design I, Boston Study Area . . .	125
50	Design II (Differences from Design I), Boston Study Area	126
51	Design III (Differences from Design I), Boston Study Area	127
52	Schematic Diagram of Systems for Disposal of Sewage and Solid Wastes	155

SECTION I

SUMMARY, FINDINGS AND CONCLUSIONS

Summary

1. Introduction. Effective water pollution control may require separate or separated collection systems, viz., wastewater systems that collect and deliver to treatment works the water-carried wastes of household and industry and storm water systems that collect and deliver to nearby watercourses the runoff from rainfall and snowmelt. Wastewater treatment works remove or modify waste substances in the carrying water to a required degree before discharging the effluent to receiving waters within or not far from the communities in which the waste matters are generated.

For historical reasons, about a fifth of the nation's population is presently served by combined systems of sewerage (Ref. 27) that collect both wastewater and storm runoff in a single set of sewers. To keep the wastewater component carried by combined collecting systems out of rivers, lakes, and tidal estuaries, the dry-weather flows of combined sewers are intercepted before they reach the terminals of the sewer system and are diverted to treatment works. Only during rainstorms and snowmelts that swell the flows of combined sewers beyond the capacity of the interceptors is a mixture of wastewater and runoff from rainfall and snowmelt discharged into the bodies of water that are otherwise protected by the intercepting system. In the Northern United States about 3% of the total annual volume of sewage and substantial volumes of wastewater solids are scoured from the sewer system during heavy runoff and are discharged to receiving watercourses through storm water overflows. The nature and extent of combined sewerage in the United States are discussed in Section II.

After the turn of the last century the danger and nuisance of combined-sewer overflows were abated in many new municipal sewerage schemes by the construction of two separate systems of sewers: a wastewater system and a storm water system. However, most of the existing combined systems were continued in service together with their interceptors except that in some instances additions to these systems were built as separate systems in which the sanitary sewers alone were connected to the existing combined sewers.

In recent years, a greater public awareness of the value of a clean environment and unpolluted natural waters, together with a desire to eliminate urban blight, has focused interest on the prevention, storage, and treatment of overflows from combined sewers. In most cases, overflows can be prevented by restricting the use of the existing combined sewers to the removal of storm water alone, or to the removal of wastewater alone. Whichever is done, it is necessary to carry the physical separation of the two systems into tributary private properties.

What is often referred to as conventional separation therefore normally involves considerable inconvenience to and disruption of normal community life by construction activities on private properties as well as on public thoroughfares. The estimated construction cost for conventional separation of the combined sewer systems in the United States that serve about 36 million people is $48 billion (Ref. 27), averaging close to $1,300 per person served. Because it recognized the high cost and disruptive nature of conventional separation, the U.S. Congress provided funds for the development of alternatives as part of the scope of the "Clean Water Restoration Act of 1966" (P.L. 89-753). Methods of reducing pollution from combined sewers other than by sewer separation are discussed in Section III.

2. Project Concept. As conceived by Professor Gordon M. Fair of Harvard University, the method of sewer separation with which the present report is concerned (Section II) would incorporate into existing combined sewer systems relatively small-diameter pipes which would convey the wastewater fraction under pressure to existing interceptors. The one-time combined sewers would be retained as the conveyors of storm water that would discharge to receiving bodies of water either directly through existing outlets or indirectly after passage through storm water retention or treatment tanks or underground facilities of a similar nature.

Structurally, the proposed system would begin at a grinding and pumping unit within each building served by the system. Where possible, the unit would prepare the wastewaters for delivery to the system through small-diameter tubing inserted in the building sewer and connected to a conduit inserted in and attached to the interior of the existing combined sewer. The main trunks of the branching network of pressure conduits would discharge into the existing interceptor which thus would convey only wastewaters to treatment works. The existing building sewers and combined sewers would deliver to receiving water bodies only storm water runoff from rainfall and snowmelt, together with such groundwater as entered the system from the soil.

In the creation of the proposed separate wastewater system, construction activity and traffic disruption would be greatly reduced by using the pipe-within-a-pipe concept or, where necessary, by installing the relatively small-bore piping in shallow trenches exterior to the combined sewers. If total costs were less than for conventional separation, the scheme would constitute a viable alternative to conventional separation. By excluding seepage waters from pressurized reaches the hydraulic loads on interceptors and treatment works would be reduced accordingly. In addition, an inherent potential advantage of pressure sewerage is that the piping is free from the limitations of gravity systems which must constantly slope downward no matter what the surface topography.

To minimize and, in so far as possible, prevent the clogging of tubing, conduits and auxiliary fittings, Professor Fair's concept included the grinding of sewage solids and pressurization in a single assembly at each building in which surges of peak flows would be attenuated by storage of incoming flows from the building served. Each residential building or structure with similar flows, therefore, would have a "storage-grinder-pump" unit.

3. Project Scope. With the support of an FWPCA contract, the American Society of Civil Engineers (ASCE) conducted an investigation of the feasibility of Professor Fair's concept. The present report contains the results of that investigation, which had the benefit of the counsel of an advisory committee called the Project Steering Committee. The principal project concerns were: (1), the development of an assembly of workable and dependable systems components; (2), a study of the physical feasibility of hypothetical pressure systems introduced into existing combined sewerage districts; and (3), a cost analysis of the hypothetical systems.

Because there was little, if any, direct information on pressurized sewer systems of this kind, it was necessary to develop required design criteria and procedures, construction methods and installation techniques, workable systems devices and parts, general system designs and other supporting information. The following example illustrates one of the required developments. Although engineering interest in pressure sewerage for a variety of applications is by no means new, lack of a suitable household storage-grinder-pump unit stood in the way of the effective utilization of pressure systems in residential areas. Accordingly, the development of a suitable storage-grinder-pump unit became a focal point of interest of the project.

Assistance was sought from organizations and individuals that were experienced in related fields. In the course of the work assistance was received from over a hundred individuals in almost fifty organizations (Section XV).

The Project Steering Committee recognized the principle that research findings should be useful for future pressure sewer applications both within and beyond the immediate Project concept and that, to this end, the Project studies should be as broad as time and funds would permit. The studies accomplished in this spirit are documented in detail in a series of twenty-five technical memoranda and reports (see Section XVI and Appendices) totaling close to 1,500 pages.

Findings and Conclusions

1. Findings and Conclusions on the Feasibility of Grinding, Storing and Pumping Domestic Sewage. The feasibility of storing, grinding and pumping sewage from individual residences has been established. The final phase of development of the household storage-grinder-

pump unit and its associated field testing is in progress in a follow-on project by the New York State Department of Health under an FWPCA grant (Section XIV).

In reference to the operation of comminuting and pumping installations serving commercial buildings, multiple dwellings, and other large sources it is concluded that the use of standard equipment on services of this scale in pressurized systems will be satisfactory.

It is recognized that there is still room for the development of suitable storage, grinding and pumping equipment for duties lying between those of individual households and large sources. However, some recently introduced assemblages appear to be suitable.

2. Findings and Conclusions on Systems of Pipes Inserted in Existing Conduits. The question of inserting and securing tubing and piping in combined sewers required evaluation of: methods of threading tubing through building drains and sewers and suspending conduit in street sewers (Section VII); and the effect of inserted conduits and their hangers on the hydraulic capacity of intruded combined sewers (Section VIII).

The Project studies and demonstrations showed that pressure tubing can be pushed and pulled through existing building drains and sewers, and that acceptable types of tubing are available.

A single-piece molded plastic hanger was developed for suspending pressure conduits inside combined sewers and found to be structurally adequate. However, it was discovered that field-insertion of conduits in hangers bonded in place was an awkward and complicated task. In this connection, furthermore, laboratory flow tests demonstrated that within a certain range of ratios of the conduit diameter to the sewer diameter, the protrusion of the portion of the hanger adjacent to the conduit unduly decreased the hydraulic capacity of intruded combined sewers. It is concluded that since the main feature of the hanger is its bonding system, a conventional metal-strap loop and suspension rod can be used satisfactorily in conjunction with the original plastic hanger seat, which will facilitate installation and minimize the diminution of intruded combined sewer hydraulic capacity.

Hanger installation was found to require direct access to the interior of combined sewers, thus limiting the installation of conduits to sewers that can be entered by workmen. This conclusion restricts the pipe insertion concept to about one-seventh of the total length of combined sewers in major cities and to a still lower proportion of such sewers in smaller communities. However, there are sectors of communities with large combined sewers and so much congestion of underground utilities and street traffic that installation of an additional system of sewers is not economically feasible unless the required piping is installed in the existing sewers. This is not to say that separation is the only way to reduce pollution from overflows. Alternatives do exist and are being investigated currently (Section III).

3. Findings and Conclusions on the Cost of Separation by the Project Scheme Versus Conventional Means. The feasibility and cost of the Project scheme were investigated by designing pressurized sewer systems for three areas of reasonable size (Section IX) that are representative of many existing combined sewer systems, as follows: (1) a 53-acre commercial downtown area in Boston, Mass.; (2) a 157-acre mainly residential area in Milwaukee, Wis.; and (3) a 323-acre predominantly residential area in San Francisco, Cal. For purposes of comparison, conventional separation of the test areas was studied by consultants in the cases of Boston and Milwaukee and by the Department of Public Works in the case of San Francisco.

Much background information had to be collected or developed before suitable designs could be prepared. Examples of required information are: expected residential and commercial sewage flows (Section IV); conventional equipment and controls for storing, grinding, and pumping sewage from commercial buildings and other large sources (Section VI); search for and testing of suitable tubing, piping and fittings, and methods for their installation (Section VII); identification of the configurations of collection systems amenable to proper operation and maintenance (Section VII); satisfaction of requirements for overall system pressure controls and pumps (Section VII); and determination of minimum solids transport velocities (Section VII).

It is estimated that construction costs for separation of these three test areas by the ASCE Project method might cost about 50% more than their separation by the conventional method of laying a second system of gravity conduits. These estimates did not take into account the inconvenience and loss of business that would be associated with conventional separation.

Whereas the unit cost of separating the plumbing systems of buildings might be lowered by including all conversions in a single contract, the structurally variegated requirements and special situations bound to be encountered in such work (Section X) would probably operate against a substantial cost reduction. This is an important consideration because this work represents some 40% to 60% of the total cost of conventional separation of the three study areas. Because the cost of building separation was quite similar for the two methods in these instances, the net competition in construction costs between pressure and gravity systems was thereby restricted to the remaining 60% to 40% of the total cost of conventional separation.

Operation and maintenance would presumably be more expensive for a pressure system. Estimates of annual costs for the Milwaukee study area, including operating costs and amortization of construction costs, were about 85% higher for the pressure scheme than for conventional separation.

It is not possible without further study to determine the typicality of the cost estimates for the three study areas on a national basis. Because much care was exercised in selecting these areas as reasonably typical, the results obtained suggest that the Project scheme will generally cost more than conventional separation. However, although the Project scheme was not found to offer a general and direct means to lower the cost of sewer separation, it was recognized that there are special situations in which existing systems or parts of systems can be separated most effectively by the ASCE Project method or a suitable modification of that method (Section XII).

4. Findings and Conclusions on the Physical Feasibility of the Project Scheme for Other Applications. Inherent in the successful first-phase development of the household storage-grinder-pump unit is the promise of the technological feasibility of pressurized sewer systems for residential areas. Completion of this development in the field in the near future, coupled with information on materials, procedures and design criteria collected or developed in the ASCE Project, provides a further degree of freedom in the design of sewer systems. Uses for this new knowledge appear to be potentially greater for applications to purposes other than the separation of existing combined sewer systems.

There is good reason to believe that many residential communities or subdivisions of communities will eventually have to replace septic tanks with public sewerage. Some of them will find that pressure systems meet their needs best. Typical examples are: residences on steeply sloping shores; areas encumbered by physical barriers such as escarpments and swamps; isolated pockets of low land; areas of undulant terrain; buildings from which wastewaters must be lifted to the level of existing gravity sewers; and areas of dispersed occupancy such as semi-rural areas.

Most of the examples cited have some bearing on new sewerage construction. In the leap-frog development of suburban areas, for instance, installation of light-weight pressure conduit by plowing techniques at shallow depth becomes relatively inexpensive and easy. Such pressure systems can then serve isolated new developments and subsequently be linked into the community system, whether it be a gravity or a pressure system.

A promising future use of pressure systems is the full exploitation of utility corridors, called "utilidors." These corridors beneath city streets conserve and make efficient use of underground space particularly where streets are burdened with heavy traffic, both vehicular and pedestrian. They also simplify maintenance, repair and replacement of the utilities they shelter. Inclusion of gravity sanitary sewers in utilidors would force the placing of the utilidors at the grades required for the sewers. This is a profoundly restrictive requirement except where needed sewer slopes and ground-surface slopes happen to be reasonably parallel. The use of pressure sewers would lift this constraint from utilidors in the same way as it commonly does from water mains. Utilidors, incidently, are important features of cities in the far north where perma-frost otherwise imposes severe restrictions on water supply and sewerage.

Lastly, some thought has been given in the Project study to the potential of extending the Project concept to the selective isolation, grinding, and wastewater transport of essentially all readily decomposable organic waste substances from households and industries to existing, enlarged, or integrated new waste treatment works (Section XIII).

SECTION II

INTRODUCTION

What Is Combined Sewerage?

Combined sewer systems that collected sanitary sewage flows together with storm water flows and dry-weather infiltration were constructed in Europe during the first half of the 19th century and somewhat later in the United States. Responsible for this action was the rapid growth of cities during the industrial revolution and the consequent overtaxing of arrangements for removal of night-soil and other wastes. Existing storm or surface water drains were pressed into service to carry off both liquid and solid waste matters to nearby streams, lakes and coastal waters. When the receiving waters were no longer able to accept the waste matters without nuisance, they themselves were either converted into underground drainage canals or otherwise protected by the introduction of marginal intercepting drains or interceptors.

The first municipal combined system of sewerage was designed and built for this purpose "from the ground, up," at Hamburg, Germany, in 1843. The first such system in the United States was completed at Brooklyn, N.Y., in 1857. About ten cities were served in this manner before the Civil War, and about 200 more systems were built in the next twenty years.

The first intercepting system of sewers was introduced into the Boston main drainage scheme in 1877-1884. It intercepted flow from combined sewers emptying into Boston Harbor and adjacent waters along the periphery of the peninsula on which much of the city was situated. Fecal matter had been excluded from existing drains by city ordinances until thirty-five years earlier. The Main Drainage scheme still serves the core city which, incidentally, includes the Summer Street district studied for separation by the ASCE Project scheme. (See Section IX).

Many engineers hold that the present public concept of the nature of overflows from combined sewers is incorrect and that the inherent purpose of such systems to discharge sewage to watercourses by design is not understood. The true nature of combined sewer systems is masked by the use of euphemistic terms that seem to subscribe to the accidental and infrequent nature of overflows of mixed sewage and storm water. Terms such as "overflow" and "spill," "bypassing of excess flows" and "relief outlets," tend to give the impression that discharges are infrequent and of an unusual or emergency character.

The definitions of intercepting sewers and regulators in the Water Pollution Control Federation (WPCF) glossary also imply the casualness of such discharges, thus:

> INTERCEPTING SEWER — "A sewer which receives dry-weather flow from a number of transverse sewers or outlets and frequently additional predetermined quantities of storm water (if from a combined system), and conducts such waters to a point for treatment or disposal."
> (This implies that the intercepting sewer receives all the sanitary sewage plus some storm water.)
>
> REGULATOR — "A device or appratus for controlling the quantity of sewage admitted to an intercepting sewer or a unit of a sewage treatment plant."
> (This suggests that the regulator passes only a portion of the flow of mixed sanitary sewage and storm water. The balance, large or small, must discharge to the local watercourse.)

The importance of possible discharges of mixed sewage and storm water flow to receiving streams is illustrated diagrammatically in Fig. 1. As there shown, almost all the sanitary sewage is discharged to the watercourse rather than to the intercepting sewer when rainstorms are heavy and prolonged. At the same time, sludge and debris that have been deposited or stranded in combined sewers during relatively low rates of flow in preceding dry-weather periods are scoured from the laterals and trunk sewers of combined systems and are lifted or otherwise transported by the augmented flows and eventually discharged to the receiving waters. It is estimated that, in consequence, as much as 5 per cent of the annual flow of sewage, and 20 to 30 per cent of the annual volume of solids, are discharged to receiving watercourses from combined systems.

Runoff rates of about 1/2 inch per hour or more are estimated to occur in the northeastern United States about 2½ to 3% of the time in the critical six-month period of June-November inclusive, for a medium sized district of about 200 to 500 acres in which roofs and pavements constitute about 80 to 90% of the area.

Ejection of mixed flows does not occur at a single level of storm runoff. It depends instead on the specific characteristics of individual overflow structures or regulators and on circumstances such as: (1) the capacities of upstream combined sewers and downstream intercepting sewers relative to runoff rates; (2) the behavior of regulating devices relative to the elevation of overflow weirs or their settings; (3) existence and state of repair of backflow gates; (4) types of control devices and their actuation relative to water levels in the combined sewers and interceptors; and (5) distribution of excess rainfall over significant or different subdistricts of tributary drainage areas.

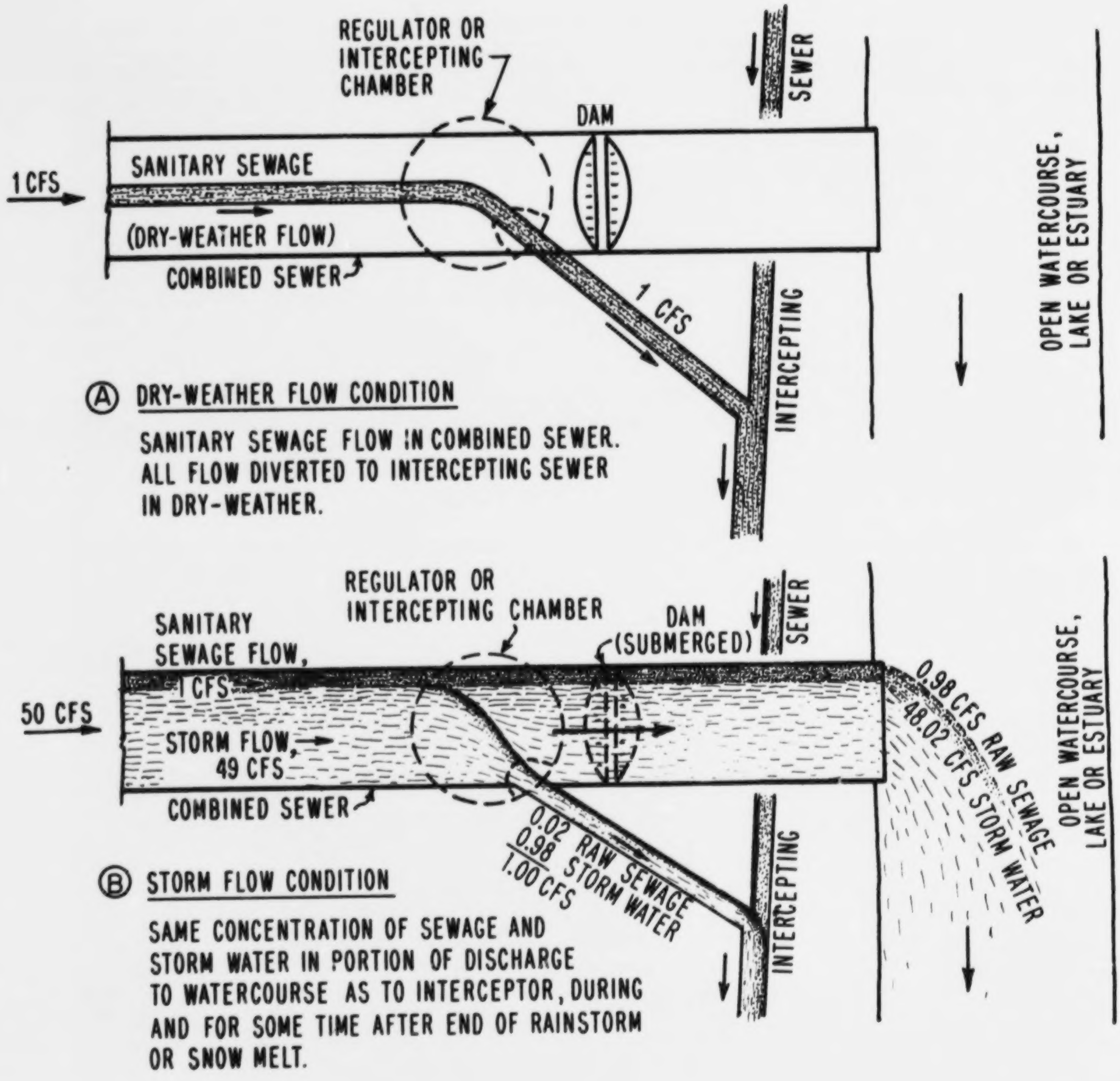

REGULATOR OR INTERCEPTING CHAMBER
DAM
SEWER
1 CFS
SANITARY SEWAGE
(DRY-WEATHER FLOW)
COMBINED SEWER
1 CFS
INTERCEPTING
OPEN WATERCOURSE, LAKE OR ESTUARY
Ⓐ DRY-WEATHER FLOW CONDITION
SANITARY SEWAGE FLOW IN COMBINED SEWER. ALL FLOW DIVERTED TO INTERCEPTING SEWER IN DRY-WEATHER.
REGULATOR OR INTERCEPTING CHAMBER
DAM (SUBMERGED)
SEWER
SANITARY SEWAGE FLOW, 1 CFS
50 CFS
STORM FLOW, 49 CFS
COMBINED SEWER
0.02 RAW SEWAGE
0.98 STORM WATER
1.00 CFS
INTERCEPTING
0.98 CFS RAW SEWAGE
48.02 CFS STORM WATER
OPEN WATERCOURSE, LAKE OR ESTUARY
Ⓑ STORM FLOW CONDITION
SAME CONCENTRATION OF SEWAGE AND STORM WATER IN PORTION OF DISCHARGE TO WATERCOURSE AS TO INTERCEPTOR, DURING AND FOR SOME TIME AFTER END OF RAINSTORM OR SNOW MELT.

FIGURE 1
DIAGRAMMATIC EXAMPLE OF NORMAL FUNCTIONING OF TYPICAL COMBINED SEWER SYSTEM UNDER DRY-WEATHER AND STORM FLOW CONDITIONS

Generally speaking, the quantities of biochemical oxygen demand (BOD) and suspended solids (SS) in the storm water runoff are normally overshadowed by the BOD and SS in the dry-weather sludge accumulations scoured from combined sewers by higher velocities of flow during rainstorms or other flood flows. Consequent ejection to watercourses of this sludge, equivalent to about one third of the untreated, partially digested, and possibly septic sanitary sewage solids, is the real objection to combined sewers.

Spills from combined sewer systems of mixed sanitary sewage and storm water, as well as scourings from sewer deposits accumulating between storm rainfalls, have long been recognized as major sources of pollution of inland watercourses and lakes, and of estuaries and bays of the oceans.

Extent of Combined Sewerage in the United States

The 1967 report, "Problems of Combined Sewer Facilities and Overflows," by the American Public Works Association, (Ref. 27), estimates that more than 1,300 jurisdictions in the United States, with a total population of about 54 million and an area of more than 3 million acres, are served in whole or in part by combined sewer systems and that the households of at least 36 million people are connected exclusively to combined sewers.

No less than 14,212 points of discharge to watercourses, lakes and coastal waters were identified in the 641 jurisdictions surveyed in the APWA study. Of these, 9,860 were outlets from combined sewers in 493 jurisdictions. Noted, too, were 759 outlets from combined-sewer pumping stations. The balance was made up of sanitary sewage overflows from pumping stations, treatment plant bypasses and miscellaneous sources.

The report places the estimated construction cost of providing existing combined sewer systems with the additional conduits needed for the creation of separate systems for (1) sanitary and industrial wastes and (2) storm water at about $30 billion and suggests a further cost figure of $18 billion for the associated separation of plumbing systems on private properties. Alternative means of control with or without treatment facilities were estimated to cost $15 billion, without the need for plumbing separation. (Alternative control measures are enumerated in a succeeding paragraph and some of these alternatives are discussed in the next section).

For historic reasons, combined sewer systems are concentrated mostly in four regions of the United States: the Northeast States, the Great Lakes Region, the Ohio River Basin and the North Pacific Coast area.

All too few of the systems studied had monitored the quantity and quality of their combined sewer overflows.

Excerpts from the conclusions of a report issued by the U.S. Public Health Service in 1964, (Ref. 28), provide the following additional information:

> "Existing sewer systems are inadequate to handle water and stormwater without creating excessive overloads at treatment plants and throughout the sewer systems, and as a result these overloads are discharged to the available water courses.
> Stormwater and combined sewer overflows are responsible for major amounts of polluting material in the Nation's receiving waters and the tendency with growing urbanization is for these amounts to increase.
> Both combined overflows and stormwater contribute significant amounts of pollutional materials to watercourses. These discharges affect all known water uses adversely in the receiving watercourses.
> Significant economic loss results from the damages caused by these discharges although precise levels of these damages remain to be determined.
> Damages occur more frequently during the summer storm season but many systems are so overloaded that overflow occurs during dry weather throughout the year.
> Infiltration is a major problem contributing to hydraulic overloading of sanitary, combined and storm sewers.
> Complete separation of stormwater from sanitary sewers and treatment of all waste is the ultimate control measure to provide maximum protection to receiving waters.
> Other solutions which have been considered, separately or in combination, include: (a) partial separation of roof, yard, areaway, foundation, and catch basin drains from sanitary and combined sewers; (b) expanded or new treatment facilities; (c) holding tanks, with or without chlorination; (d) disinfection; (e) storage using lagoons, lakes, quarries and other depressions; (f) storage using guttering, streets and roadways, and inlets; (g) additional sewer capacity; (h) regulation and control of flow through the sewer system; and (i) improved planning and zoning.
> Evaluation of the effectiveness of all methods except complete separation is unavailable because of the lack of installations to study."

The Proposed Project of Study

The underlying concept of the sewage separation scheme using pressure tubing was originated by Gordon M. Fair, Professor of Sanitary Engineering at Harvard University, and made public in mid-summer of 1965. Professor Fair filed a patent application through the Harvard Corporation in November 1965 for a "Converted Sewer System." Patent No. 3,366,339 was granted in January 1968, and assigned to the public by the inventor.

Section XVII is a facsimile of the patent text and drawing. Patent No. 3,211,167 for "Apparatus for Transporting Sewage and Waste Liquids" (via pressure sewerage) was granted to M.A. Clift, et al on October 12, 1965.

The immediate objective of the project was to examine and evaluate the feasibility and probable cost of the separation systems suggested by Professor Fair. This objective was pursued from the standpoint of applied research. Modifications and alternative schemes were introduced in the course of the studies.

Study and expansion of the concept was undertaken by the American Society of Civil Engineers (Ref. 1), acting through its Executive Secretary, Mr. W.H. Wisely, and its Research Manager, Mr. D.C. Taylor. General overview of the project was provided by the Urban Hydrology Research Council of the ASCE Hydraulics Division, and immediate and overall guidance was assumed by a Steering Committee of seven members of the Society under the Chairmanship of Professor Fair. The membership of the Committee is listed in Section XV of this report. Steering Committee liason was maintained with the Water Quality Research Council of the ASCE Sanitary Engineering Division by a contact member, Mr. Richard Hazen. The Project was directed by Mr. M.B. McPherson, assisted by Messrs. L.S. Tucker and D.H. Waller.

The plan of research is outlined diagrammatically in Fig. 2. As shown, component elements of the problem were categorized as (1) development of devices for storage, grinding and pumping at buildings, (2) provision of design criteria for street pressure sewerage, (3) ways and means for inserting tubing in building service connections and in conduits suspended in street sewers, and (4) ancillary considerations.

From the outset, the project management approach was to maximize assistance from knowledgeable organizations and individuals experienced in the specialized subjects relating to the project. In the course of the work, various levels of assistance were provided by over a hundred individuals from almost fifty organizations, including officials of municipal water pollution control agencies, representatives of manufacturers, members of firms of consulting engineers, and staff members of trade and professional associations.

Because of the paucity of immediately helpful precedent, equipment assemblage of compatible materials, methods of installation and maintenance and establishment of design criteria founded on fundamental data were based on experiment and trial.

In evaluating the feasibility and general acceptability of the methods for pollution abatement studied in the ASCE Project it was assumed that the following criteria for judgment should be applied: (1) the merits of the system in terms of physical capability of construction and operation of the system to accomplish the desired results; and (2) the relative economy of the construction effort compared with

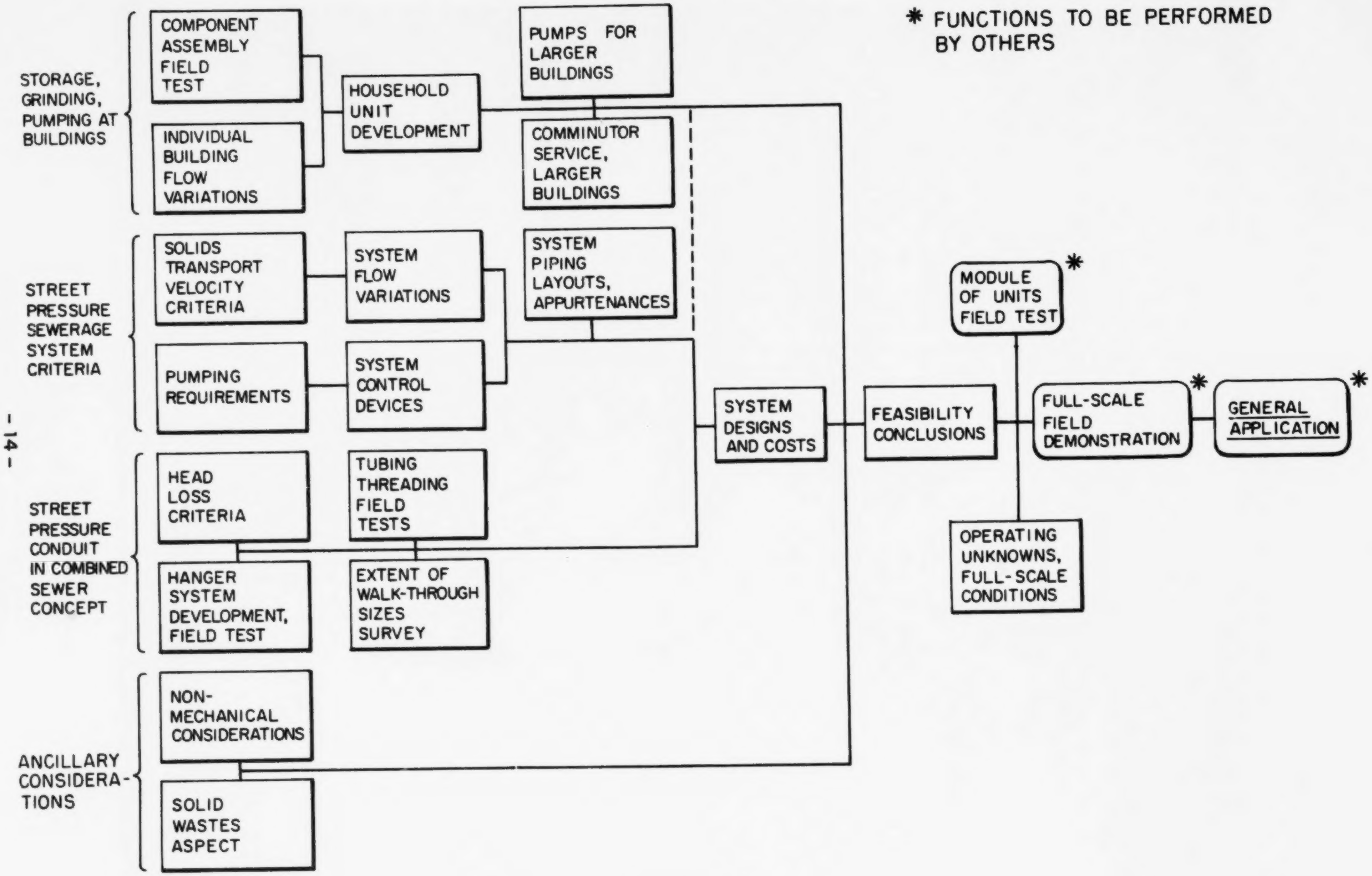

* FUNCTIONS TO BE PERFORMED BY OTHERS
STORAGE, GRINDING, PUMPING AT BUILDINGS
COMPONENT ASSEMBLY FIELD TEST
INDIVIDUAL BUILDING FLOW VARIATIONS
HOUSEHOLD UNIT DEVELOPMENT
PUMPS FOR LARGER BUILDINGS
COMMINUTOR SERVICE, LARGER BUILDINGS
STREET PRESSURE SEWERAGE SYSTEM CRITERIA
SOLIDS TRANSPORT VELOCITY CRITERIA
PUMPING REQUIREMENTS
SYSTEM FLOW VARIATIONS
SYSTEM CONTROL DEVICES
SYSTEM PIPING LAYOUTS, APPURTENANCES
STREET PRESSURE CONDUIT IN COMBINED SEWER CONCEPT
HEAD LOSS CRITERIA
HANGER SYSTEM DEVELOPMENT, FIELD TEST
TUBING THREADING FIELD TESTS
EXTENT OF WALK-THROUGH SIZES SURVEY
ANCILLARY CONSIDERA-TIONS
NON-MECHANICAL CONSIDERATIONS
SOLID WASTES ASPECT
SYSTEM DESIGNS AND COSTS
FEASIBILITY CONCLUSIONS
MODULE OF UNITS FIELD TEST *
OPERATING UNKNOWNS, FULL-SCALE CONDITIONS
FULL-SCALE FIELD DEMONSTRATION *
GENERAL APPLICATION *

FIGURE 2
PRESSURE SEWERAGE RESEARCH PLAN FOR ASCE COMBINED SEWER SEPARATION PROJECT

that of alternative methods. Physical capability was understood to include the hydraulic design of the system, the construction of the pressure tubing and conduit system, the manufacturing and installation of appropriate grinding and pumping equipment, and the establishment of suitable maintenance facilities and staff.

The source of funds, local, State and Federal, was not considered to be a factor in the evaluation of economic feasibility.

Authorization, Scope, and Content of the Report

The studies of sewer separation covered in the present report were undertaken with the support of a contract with the Federal Water Pollution Control Administration of the Department of the Interior acting through the Storm and Combined Sewer Pollution Control Branch, Division of Applied Science and Technology, of its Office of Research and Development. The work was performed under the legal authorization of Section 6 of the Federal Water Pollution Control Act ("Clean Water Restoration Act of 1966," PL-89-753). The project, numbered 14-12-29 and titled "Feasibility and Development of New Methods of Separating Sanitary Sewage from Combined Sewerage Systems," was funded by a contract in the sum of $343,210 awarded to the American Society of Civil Engineers on February 15, 1967, following an earlier and initial study under Demonstration Grant WPD 104-01-66 dating back to February 1, 1966.

The project scope is indicated by the quotation below from the FWPCA public information release.

> "The project will determine the feasibility and applicability of installing small pressure conduits within combined (storm-sanitary) sewers as a means of separating sanitary sewage from storm water. The conduits will be used to transport finely ground sewage under pressure to interceptor sewers for conveyance to municipal treatment plants. It is anticipated that the separation of sanitary sewage from storm water will reduce the pollution load discharged to surface waters at system overflow points.
> Combination grinder-pump units will be developed for both household and some commercial uses to pre-condition wastes for discharge into the pressure conduits....."

The ultimate goal of the project was to develop feasible designs and operations for the separation of combined systems of sewerage that would abate the pollution of receiving waters from overflows of mixed sewage and storm water, and to put those measures to test by converting existing combined systems, or suitable portions of existing combined systems, into completely separated systems.

The present extent of combined sewerage and conditions requiring remedial action have been discussed herein. Alternative methods to accomplish the separation of combined systems are briefly summarized in the following section.

As described in Section III, the ASCE "Combined Sewer Separation Project" for the removal of sanitary sewage from combined sewers, was based on pumping domestic sewage from all generating sources to intercepting sewers through an independent system of tubing and pressurized sanitary sewers while retaining the existing combined sewers as separate storm drainage conduits that discharge only storm water to receiving watercourses.

The details of grinding or comminution, storage and pumping are explained in Sections IV through VII.

Sections VIII and IX contain the results of studies on the effects of installing pressure tubing in existing building connections and larger pressure conduits in street sewers; feasibility studies based on introducing the proposed system into three existing combined sewer districts, including required separation of existing building plumbing; and pertinent non-technical considerations.

The advantages and disadvantages of the ASCE Project system are evaluated in Section XII, together with the application of devices and techniques developed under Project sponsorship to sewerage purposes other than those of separation of combined sewers; possible application of project equipment and techniques to sewers for the transportation of solid wastes is discussed in Section XIII; and proposed tests of household storage-grinder-pump units in an installation involving a dozen homes, and a projected large-scale field demonstration are described in Section XIV.

The information from the study was reported initially in a series of ASCE Combined Sewer Separation Project Technical Memoranda, and in eleven technical reports, submitted to and approved for distribution by the Project Officer, Contract No. 14-12-29, for the Federal Water Pollution Control Administration. These memoranda and reports are listed by title in the Bibliography (Section XVI) as References 1 through 26, inclusive. Appendix A contains abstracts of the technical memoranda and Appendix B contains abstracts of the reports.

Opinion Survey

A survey of the eleven largest cities of the United States equipped with fully-combined or partly-combined sewer systems was made in 1966 by ASCE project staff engineers (Ref. 15) in consultation with city water pollution control officials. The most frequent comments of these officials can be summarized as follows:

> Complete, conventional separation of a combined sewer system is a clearly definable objective only when the combined sewers are of adequate capacity for at least contemporary storm drainage requirements. In several cities extensive areas are served by combined sewers with inadequate storm drainage capacity. In many cases inadequacy is based, in some degree, on the upgrading of design standards since World War II. Land-use practices, not anticipated when these sewers were designed, are major contributing factors. In these instances the separation of sanitary sewage is inextricably tied to storm-water flooding relief.

Virtually all officials noted that, like conventional separation, the ASCE Project scheme would not change the quality of storm water discharged directly to receiving watercourses except for the non-inclusion of bottom deposits traceable to the previous transport of solids of domestic and industrial origin. It was noted that current national interest in pollution abatement had extended from concern for diversion of all sanitary sewage to treatment plants to include reduction in pollution from storm drainage.

The reservations of city officials about the efficacy of conventional separation and directly comparable alternatives are echoed as follows in Reference 35: "The separation of storm and sanitary sewers has been recommended but recent evidence indicates that the contamination from streets, sidewalks, and city surfaces would make the runoff from rains quite a pollutant to receiving waters, even if it did not contain sewage. Therefore, the very expensive reconstruction of city sewer systems would not yield comparable increases in quality in the receiving water. ..... Evidence is now accumulating that the separation approach would have very little benefit for the quality of receiving waters even if it could be accomplished." Detention and treatment basins for combined-sewer overflows are of paramount current interest because they have the potential of reducing the pollution from overflows at possibly much less attendant costs than the separation of existing sewer systems.

Officials in one city were of the opinion that, little by little, major cities are being rebuilt, separate sewers are becoming part of nearly all new construction, and in another 50 years or so existing combined sewer systems will have been largely eliminated. The virtue of a crash program of sewer separation under the constraints of prevailing and foreseeable land-use was therefore questioned.

Several officials recognized that the problems for which solutions are being sought have not been adequately defined, that "more research is needed to develop understanding of the whole storm water pollution problem," and that "this research should cover the hydrology, the hydraulics, the treatment, the effects on recovery waters, and related factors." (Ref. 36).

Although some officials conceded that feasible and acceptable methods and devices might be developed for introducing pressure conduits into walk-through size combined sewers (about 54 in. in height or larger), firm reservations were expressed on the introduction of pressure conduits into smaller sewers. Development of suitable installation techniques was considered a formidable problem, but objections were directed more specifically to difficulties of maintenance, repair, and replacement of such systems. Included in particular, was the possibility that inserted conduits or tubing would aggravate the accumulation of debris; that the intruding services would interfere with free movement of sewer cleaning devices; and that conduits, tubing, and connections would not be conveniently accessible for repair, for the connection of new building services and for the inevitable long-term replacement of necessary parts of pressurized systems. Although major skepticism was voiced in regard to pressure conduits in non walk-through sewers, there was opposition also to the presence of 3/4-in. to 1 1/4-in. I.D. plastic tubing in a building sewer because it would accentuate clogging by roof debris and interfere with the operation of cleaning devices and the cutting of tree roots.

There was concern about ownership of necessary storage-grinder-pump units, the relative merits of municipal versus private ownership, the attainability of adequate home-owner acceptability and related aspects of equipment maintenance and necessary provisions for overloading conditions. Prevention of backflow into buildings and protection against overflow from household storage-grinder-pump units during power outages was a major consideration.

On the basis of cost estimates covering ten of the cities, projected to the requirements of the United States as a whole, tentative estimates for conventional separation of combined sewer systems were as high as $100 billion, including allowance for debt service.

Accounts of other surveys are contained in Ref. 37 by Gannon and Streck, 1967.

An indication of the relative length of various combined sewer size ranges is given in Technical Memorandum No. 4, 1967, Ref. 4. An average of about 15% of the total combined sewer mileage in major cities is 54-in. in height or larger, generally considered to be the walk-through size range. This percentage is apparently even smaller for cities with a population of 100,000 or less.

SECTION III

ALTERNATIVE METHODS OF REDUCING POLLUTION FROM COMBINED SEWER OVERFLOWS

Introduction

That plans for protecting receiving waters against pollution by overflows from combined sewers connected to interceptors take many forms, is shown by the extensive bibliography included in this report.

The currently most promising measures of control are discussed briefly in the present section. Some of them are complete within themselves; and others must be fitted into related schemes. In many instances, moreover, different measures may be most suitable for individual sub-areas of existing sewer systems, the choice of measures depending on the type of development, the topography of the community and the many other factors entering into the design of effective drainage schemes.

Complete Separation of Existing Combined Systems

The designer is offered the following two choices for the separation of existing fully combined sewer systems that are connected to interceptors:

1. Conversion of all or part of the existing scheme into a storm water system and addition *in toto* or in part of a complementary system of sanitary sewers. Normally this will require the retention of existing catchbasins as storm water inlets and the separation of existing roof and yard drains from house drainage piping and their connection to the storm water system.

2. Conversion of all or part of the existing scheme into a sanitary sewer system and addition *in toto* or in part of a complementary system of storm water sewers. Normally this will require the retention of existing house sewers and the separation of roof and yard drains from the house drainage piping and their connection as well as that of catchbasins or street inlets to the storm water system.

Choice will be determined by the projected relative effectiveness and cost (1) of the existing system as a storm water or a sanitary sewer system and (2) of the added complementary sanitary sewer or storm water system. Either choice is referred to as traditional, common or conventional separation.

Many existing systems are composed of (1) combined systems generally constructed before the turn of the century and serving the older, downtown, or core areas of the community and (2) separate systems generally constructed after the turn of the century and serving the newer, peripheral, or suburban areas of the community. In partially separated systems of this kind, the sanitary sewers are normally connected to regional or zonal mains that terminate in the interceptors or outfalls of the existing combined but intercepting system.

Construction of the separate portions of sanitary or storm water sewers (1) would entail excavation and repaving in nearly every street and circumvention of existing utilities and subways, and (2) would result in massive interference with traffic and the movement of pedestrians and often, too, in substantial business losses.

If it is completely accomplished, either method of separation of existing combined systems or combined portions of existing systems would eliminate, within the limits of the capacity of the intercepting system, all overflows of municipal and industrial wastewaters to receiving waters. Estimated costs of separation are given in Section IX for three comparative studies of conventional separation on the one hand and the ASCE project scheme on the other hand.

Partial Separation of Existing Combined Systems

Partial separation of storm water flows from combined systems by the addition of a storm water system to the existing combined sewer system which is retained in operation, is a less expensive but understandably also less effective alternative to complete separation. Auxiliary storm water conduits are built to intercept storm runoff from street and large paved surfaces, such as parking lots, before the runoff can reach the inlets to the existing combined system. The demand on the combined system is thereby reduced by diversion of readily separable surface runoff to local watercourses and lowers the frequency of occurrence and duration of flow rates in excess of interceptor capacity. Partial separation is sometimes employed as a means of enlarging the storm flow capacity of sewers in areas where existing combined sewers have proved inadequate for rainfalls of frequent occurrence.

How beneficial partial separation of this kind can be is determined by the capacity of existing components of combined and intercepting sewers. The supplemental storm water system normally relegates construction of large-sized additional pipes to busy downtown streets, and incurs the associated difficulties of construction, disruption of normal community life, and possible financial losses. At the penalty of reduced effectiveness, building plumbing is not separated from the remaining combined system in this scheme of partial separation.

Retardation or Storage of Interceptor Overflows

The provision of off-system and intra-system storage reservoirs, holding tanks, or retardation basins that reduce peak rates of runoff to acceptable values in conjunction with existing capacities of intercepting sewers creates another method of overflow control. Storage may be provided (1) in upstream reservoirs, including temporary ponds within playgrounds or other open areas that withhold storm waters from the combined system, (2) in oversized conduits within the combined sewer system, and in retention, detention, or retarding reservoirs or tanks towards the downstream end of the system, often preferably near existing storm water outlets.

Downstream storage lying between low- and high-water levels of the combined sewers, is normally intended to return accumulating volumes of wastewater to the combined sewer system or to the interceptors after the rate of runoff has diminished to a level at which stored volumes can be released in gravity flow from the tanks. Waters stored below the water levels of the combined sewer system or interceptors must be returned by pumps to the system for treatment. Necessary storage tanks are useful only when available treatment facilities are large enough, or when they can be enlarged to provide required treatment of the accumulated masses of water between storms, in addition to the normal dry-weather flows of sewage.

Holding or standby tanks have been in use for many years at Columbus, Ohio, and are being built in New York City and elsewhere. At Detroit, Michigan, stormflows being metered and dispatched within large-sized pipes offer an example of the utilization of intra-system storage. The so-called deep tunnel systems being studied and cautiously implemented at Chicago, and being recommended for the Boston area, provide very large volumes of storage.

As an alternative or augmentation to the kinds of storage cited, storm water can be diverted to groundwater by means of various land treatment methods and by groundwater disposal wells and basins.

Treatment of Overflowing Waters

Overflow discharges can be treated partially or completely before they are ejected to receiving waterways. Treatment can be provided at individual outlets, at interconnected groups of outlets, or at central locations. The number of treatment plants will vary accordingly. Depending upon the required degree of treatment, overflows might be screened for the removal of coarse and unsightly particles, disinfected for the destruction of pathogens, settled for the removal of fine suspended solids, etc. Required treatment facilities would often lie in heavily built-up high-value areas, historically located near watercourses. Plant capacities must be large enough to receive and treat the flows at expected and definable peak rates of outflow in concordance with flood-routing procedures, taking into account the attenuation of peak flows afforded by storage.

The capacities of the combined sewers must be inherently sufficient, or rendered so by the provision of adequate relief capacity. Practically all the mixed sewage and storm runoff must normally be carried to the points of treatment. Upstream overflows can normally not be tolerated. Crews and equipment must generally be on stand-by, and maintenance is normally a routine item of continuing expense. Required conduits as well as treatment works must be capable of conveying storm flows from the collection system at peak rates of discharge. They, too, may be in the high-value congested areas of municipalities. Planned or inadvertent interconnections between district sewer systems may add to difficulties of design and operation.

Other Alternatives for Reducing Pollution by Overflows

Among other alternatives of reducing the pollution of watercourses that are the recipients of overflows are: (1) segregation of trunk sewer flows by construction of pipes within pipes as has been done experimentally at Minneapolis, where large combined sewers provided excess storm water capacity; (2) reduction of sludge volumes subject to scour by storm water flows through the systematic flushing of combined sewers in dry weather, provided that interceptor capacity is large enough to transport the scourings to the treatment works; (3) addition of coagulating polyelectrolytes to mixed flows and disinfection within combined sewers; (4) separate treatment of domestic and industrial sewage flows at the source, followed by discharge of treated effluents to the combined sewers; and (5) reduction of friction losses in interceptors by the addition of polymers, thereby increasing their flow capacity.

Other provisions include: (1) the storage of wastewater flows in large combination rubberized fabric and steel tanks submerged in receiving waters at shoreline outlets as at Washington, D.C., and Cambridge, Maryland; (2) the storage of flows in enclosed portions of lakes, as at Cleveland, Ohio, and Syracuse, New York; (3) reduction of dry-weather as well as wet-weather overflows from combined sewers by better organization for efficient and effective maintenance of existing sewage regulators, design of improved regulators for more effective action and easier maintenance, and monitored and remote operation and control of regulators, as at Minneapolis and St. Paul, Minnesota; and (4) elimination of discharge of mixed flow of sewage and storm water from combined systems to local receiving waters by relocation of overflow outlets, involving their extension to points where large volumes of diluting water are available, as at Boston, Massachusetts, where an off-shore outlet beyond the limits of the outer harbor is under study.

ASCE Combined Sewer Separation Project

The foregoing discussion of separation methods currently under investigation have been presented as background information on the need and urgency of developing economical and effective methods for preventing the pollution of local watercourses and other receiving bodies of water by overflow discharges from existing combined sewers.

To these methods the present section adds a discussion of the ASCE Project, which is examined with a view to its ability to effect the same degree of separation as the conventional method without the construction of the new pipes and attendant trenching of streets of the cities and other disruptions, as well as costs.

The ASCE Combined Sewer Separation Project to study and make recommendations to the Federal Water Pollution Control Administration "on the feasibility and development of new methods of separating sanitary sewage from combined sewer systems," looks to complete separation of sanitary sewage and storm water at their sources by the use of storage-grinder-pump equipment in advance of discharging the ground and pressurized building flows through pressure tubing and conduits, where possible within existing building and street sewers.

The general concept of the Project is to pump minutely subdivided sanitary sewage from individual buildings and building groups through relatively small tubing inserted into existing building drains and sewers (the pipe within a pipe system) or laid parallel to building drains and in separate trenches adjacent to building sewers. The tubing connects to pressure conduits suspended in or laid parallel to existing street sewers, and thence into existing intercepting sewers that convey the separated sanitary sewage to treatment works.

Storm water alone is carried in the system of pipes that originally served as combined sewers and is discharged as such into available watercourses. Existing gravity building sewers remain available for transport of roof and similar storm and subdrainage flows to the street sewer (now a storm water drain) in the cross-sectional area of the gravity building drain and building sewer not occupied by the pressure tubing.

The ASCE Project scheme is based on Professor Fair's concept of a system composed of: (1) individual building tanks, grinders and pumps; (2) pressure tubing inserted in building drains and sewers; and (3) pressure piping laid within the street sewers and leading to the existing interceptors of the drainage system.

Because of the difficulty of inserting tubing through building traps where these are required; through sharp bends where they exist; and through cracked and offset pipe lengths and other possible obstructions in existing building drains and sewers; and because no methods were developed for joining tubing and conduits within small-sized combined sewers without extensive excavation, alternatives to the original concept were studied. To this purpose small combined sewers were taken to be those of less than walk-through height which was assumed to be 54-in. Alternative piping consisted of (1) tubing inserted in a building sewer as far as an obstruction and laid thence in a trench to the street main; (2) tubing laid all the way from a building to the existing street main in a trench; or (3) tubing extending from a building to a pressure conduit in the street independent of any existing sewer. Such independent conduits might be laid in trench beneath the sidewalk or at the gutter line on one or both sides of the street.

It was considered that the following functions should be accomplished:

1. Interception of domestic or industrial wastewaters at the source to remove them from combined piping. This would be effected by excluding storm or related runoff from the building plumbing system. Generally this would be effected at the principal horizontal run of pipe or pipes in the building basement.

2. Discharge of the intercepted flow from the building to the street pressure sewer through pressure tubing. This would be effected by storage-grinder-pump (SGP) household units for domestic flow rates from individual dwelling units and by comminutor-pump installations for larger installations. Solids must be reduced in size and stringy and rubbery materials must be chopped up to permit their passage through pumps, valves and tubing and to prevent the accumulation of deposits in storage tanks, and in tubing and other pressure conduits.

3. Collection of the sewage flows in a separate street pressure sewer system, and transmission to the existing intercepting sewer. This can be effected by the pressure conduit system studied if pressure-control valves are installed at the interceptors and perhaps at other points within the system. Collection may require auxiliary lift stations and control valves.

If the pressure system is to function reliably its piping must remain free of stoppages and its mechanical and electrical components in terms of pumps, grinders or comminutors, and valves must operate without trouble. The household unit must be provided (1) with a device that will prevent back-flow from the pressure system when the pump is not operating or is out of service, and (2) with an overflow outlet to the existing building drain or sewer or with an adequate alternative appurtenance for the emergency discharge of sewage to the storm water system. To safeguard the storm system against sewage entering the system because of equipment failure, and to give warning of failure, an economical signal device of some sort would be of advantage. The system must be easily maintained and repaired and its parts must be rapidly replaced.

Separation of plumbing systems is discussed in Section X. Grinding, storage, and pumping for small residential and commercial flow rates are discussed in Section V and for larger residential, commercial and industrial flows in Section VI. The insertion of pressure tubing, installation and suspension of conduits, and general arrangement of collection systems are discussed in Section VII.

Because of the lack of experience with pressure systems and limited precedent for accomplishing needed functions, other than the grinding of garbage in kitchen units, research was undertaken in the following areas:

1. Grinding and pumping domestic sewage at low rates of production.

2. Threading tubing into and through small-sized pipes such as building drains and sewers.

3. Suspending pressure conduits in sewers during times of low flow or temporary periods of removal from service.

4. Determining the magnitude of maximum and minimum rates of flow from households and groups of households.

5. Solving hydraulic problems associated with pumping liquids containing sewage solids in a collection system, as contrasted to clear water in a water distribution system.

The Project staff conducted research on all phases of the project, with the assistance of interested engineers and others, many of whom were not reimbursed. Specific examples of non-reimbursed assistance are as follows:

1. Comminuting and pumping: FMC Corporation, Chicago Pump-Hydrodynamics Division, Chicago, Ill.

2. Hypothetical applications to existing sewer systems: Public Works Departments of San Francisco, Cal., Milwaukee, Wis., and Boston, Mass.

3. Plans and arrangements for pressure tubing insertion and connection to pressure conduit in field trials: Department of Sanitary Engineering, Washington, D.C.

4. Flow and pressure control valves: BIF Division of the General Signal Corporation, Providence, R.I.

5. Plans and arrangements for field suspension of pressure conduit in walk-through sewer: The Metropolitan Sanitary District of Greater Chicago, Ill.

6. Distribution of combined sewer size categories in major cities: Portland Cement Association, Chicago, Ill.

7. Magnitude and range of variations in rates of sewage flow: Department of Environmental Engineering Science, The Johns Hopkins University, Baltimore, Md.

Research was also conducted under contract with equipment manufacturers, research organizations, and consultants in specific phases of the project, as follows:

1. Grinding, storing and pumping, and back-flow prevention: General Electric Company, Water Management Laboratory and Major Appliance Laboratories, Louisville, Ky., and Research and Development Center, Schenectady, N.Y.

2. Hypothetical applications to existing sewer systems: Brown and Caldwell, San Francisco, Cal., Greeley and Hansen, Chicago, Ill., and Camp, Dresser and McKee, Boston, Mass.

3. Pressure tubing insertion, connection to pressure conduit and overall conduit system: National Sanitation Foundation, Ann Arbor, Mich.

4. Minimum solids transport velocities in pressure conduits: FMC Corporation, Central Engineering Laboratories, Santa Clara, Cal.

5. Hydraulics of flow in eccentric annular conduits: Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

6. Magnitude and range of variation in rates of sewage flow: Water Management Laboratory, General Electric Company, Louisville, Ky.

7. Pressure conduit hanger system for walk-through sewers: Research and Engineering Center, Johns Manville Corporation, Manville, N.J.

SECTION IV

RESIDENTIAL AND COMMERCIAL SEWAGE FLOWS*

Introduction

Fundamental to the design of pressure house-connections and pressure street sewer conduits for the ASCE Combined Sewer Separation Project is reliable information on (1) rates of discharge of sewage from individual households, small groups of households, and commercial and individual sources in pressure-sewer laterals; and (2) concurrent aggregate rates of flow from pressure-sewer laterals to pressure-sewer branches and mains.

Data of this nature must be known with greater precision than for gravity piping systems because velocities in the pressure piping must (1) be above the minimum velocities at which excessive deposition of solids takes place at least part of each day and (2) not be excessive at peak flows if pressure-loss gradients and pumping heads within the capabilities of the units selected are to be maintained. By contrast, gravity sewers, which are commonly designed to flow at maximum design rates at 0.5 to 0.9 full depth, will accept higher flow rates without being surcharged.

There is little information on rates of sewage flow from individual households and commercial buildings, particularly for time intervals on the order of a minute. As a substitute, practically all of the data recorded and studied were water-supply demand-rates, based on the assumption that departures from true rates of discharge because of storage effects in household supply and drainage systems are minor and can be neglected, provided no substantial amount of water is diverted from the drainage system. This is generally true in winter in northern latitudes because little water is then used for watering growing plants, washing automobiles, and air conditioning.

Information from Earlier Studies

Staff research engineers prepared a review of published and unpublished information on flows to or from households and small commercial buildings. Special emphasis was placed on (1) information on water demands observed for groups of up to 400 households and reported by the Residential Water Use Research Project of the Johns Hopkins University (Ref. 29), (2) winter quarter-year flows in ten county areas compiled by the U.S. Public Health Service Taft Center (Ref. 30), and (3) the Farmstead Water Study of the U.S. Department of Agriculture for 11 individual households in the English Manor subdivision near Wheaton, Maryland, north of Washington, D.C., covering about a month in 1964 (Ref. 31). English Manor data had been reduced to successive minutes of use, from which peak flow demands were determined for two seven-day periods in 6 of the 11 households.

---

* Refs. 2, 8, 9, 19 and 20.

Project Studies

A search for flow rates to be used in systems design was made by the ASCE Project staff assisted by records of individual household water demands monitored in 1966 and 1967 by the Water Management Laboratory of the Major Appliance and Hotpoint Division, General Electric Company, Appliance Park, Louisville, Ky. (Refs. 19 and 20). This investigation was based on observations of water supply demand during a 4-week period at 2 households in Louisville, Kentucky. Peak water demands for various durations were determined.

Results of Project Studies

Fig. 3 shows for the USDA and G.E. observations the ratios of daily household demands to mean daily household demands plotted against the percentage of time a specific ratio was equalled or exceeded. From extrapolation of an auxiliary semi-logarithmic data plot it was found that the ratio of the daily to the mean daily demands would be on the order of 2.4 an average of twice per year compared to a ratio of 2.0 for the recorded maximum value for both sets of observations. The ratio of minimum daily demand to mean daily demand determined from the plot was about 0.7 compared to recorded minimum values of about 0.4 for both sets of observations.

For the USDA and G.E. observations Fig. 4 shows the ratios of daily peak 60-minute household demands to mean daily household demands plotted against the percentage of time the ratio was equalled or exceeded. From extrapolation of an auxiliary semi-logarithmic data plot it was found that the ratio of daily 60-minute peak to the mean daily demand would be on the order of 13 an average of twice per year, a value in the neighborhood of the recorded maximum values for both sets of observations.

Ratios of peak daily household demands to mean daily household demands for shorter periods of flow were developed. The results for daily, 60-minute, 15-minute and 4-minute periods are shown in Table 1.

To augment data for the design of pressure sewer laterals serving more than a single household source, demands for groups of three and six houses were analyzed using the USDA data. The results of these analyses are shown in Fig. 5 and Table 1. Typical attenuation of peak ratios with increase in number of services is evident.

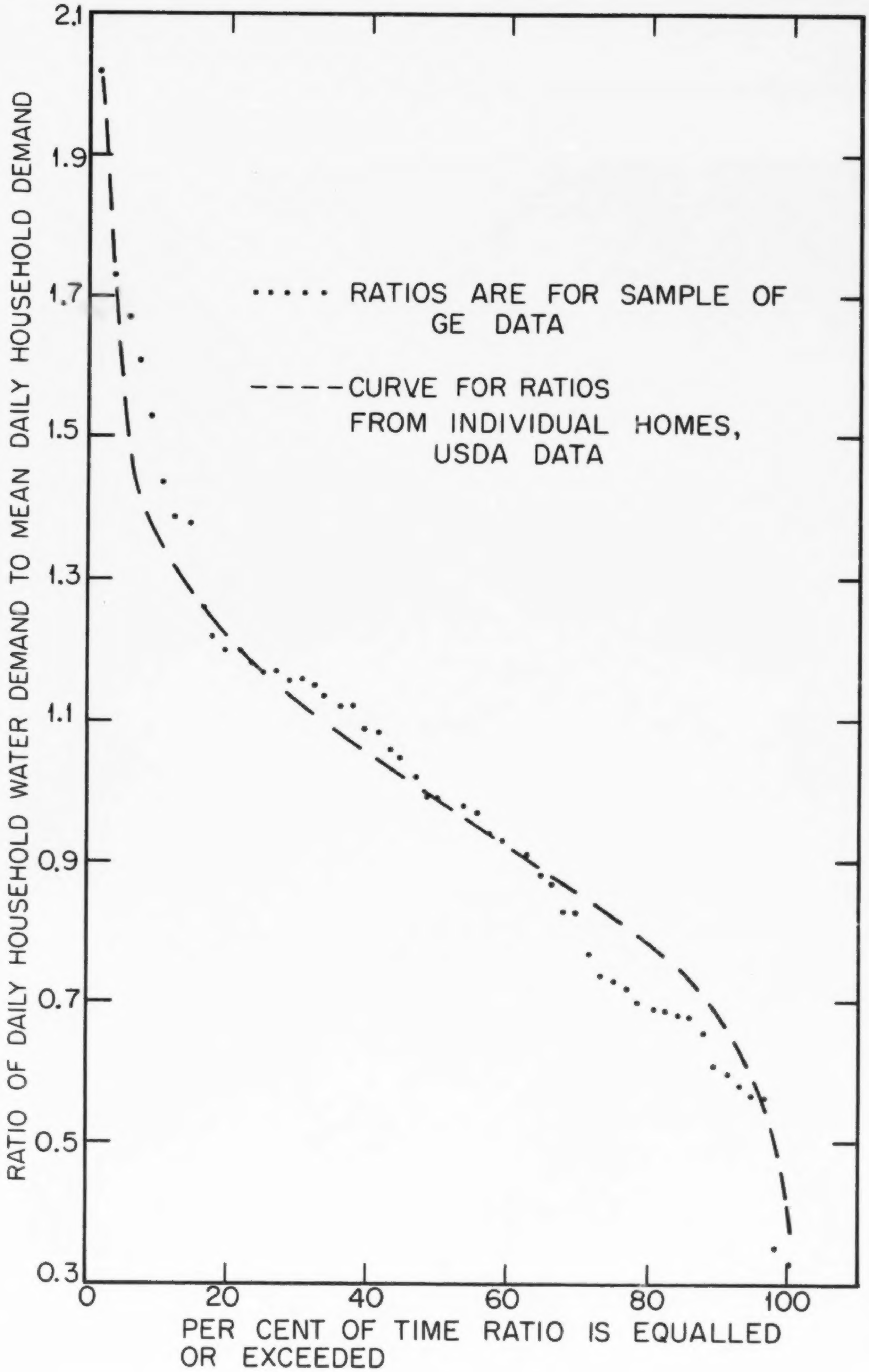


FIGURE 3

VARIATION IN DAILY WATER USE (Modified from Fig. 2, Ref. 2)

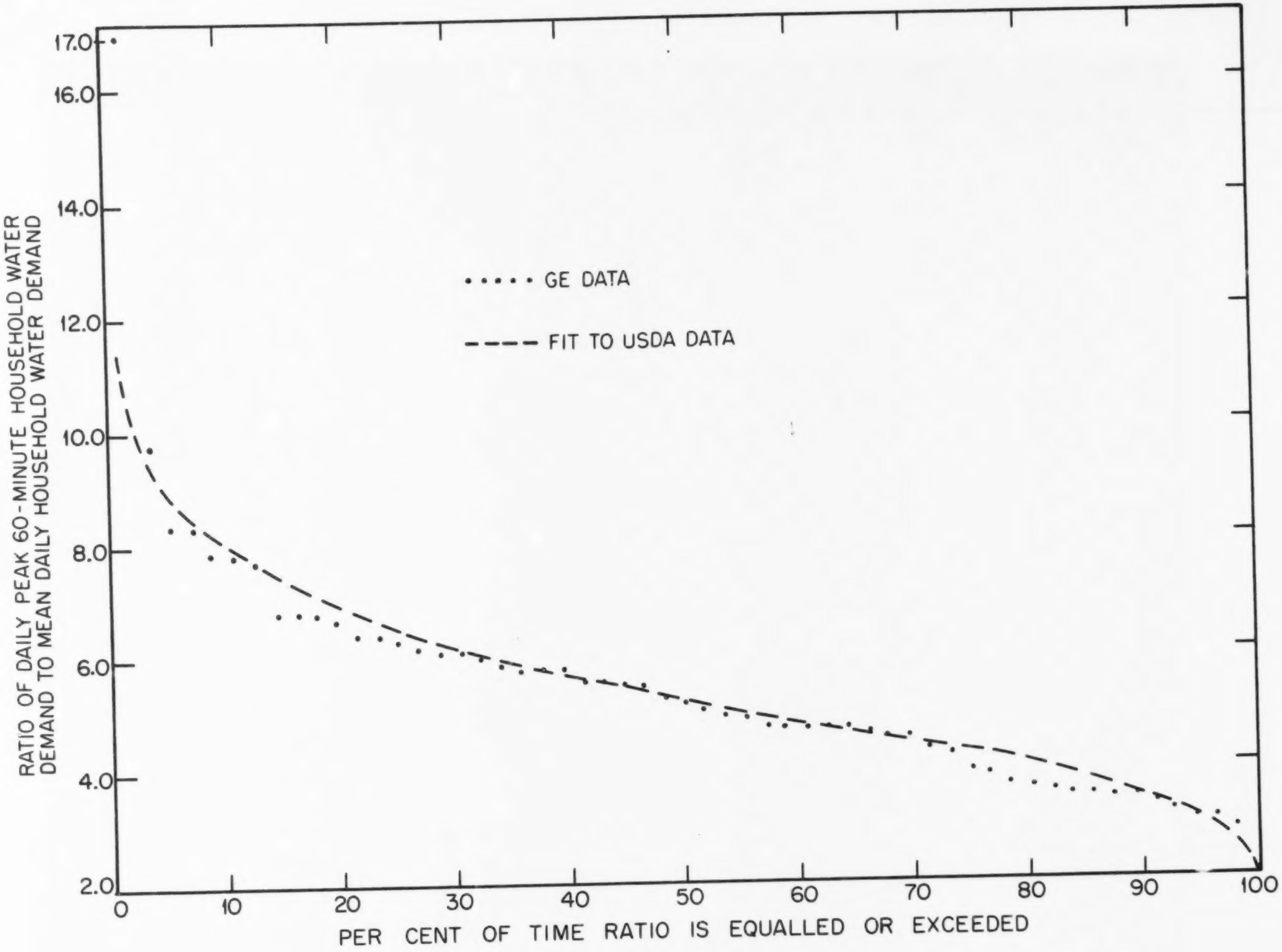


FIGURE 4
VARIATION IN PEAK HOUR WATER USE (Modified from Fig. 4, Ref. 2)

TABLE 1

RATIOS OF HOUSEHOLD WATER DEMAND RATES FOR VARIOUS PERIODS TO MEAN DAILY HOUSEHOLD WATER DEMAND RATES

Source	Ratios for Daily Demands				Ratios for Peak 60-Min. Demands				Ratios for Other Peak Demands	
	Maximum		Minimum		Maximum		Minimum		Peak 15-min.	Peak 4-min.
	Observed	Expected an Average of Twice Per Year	Observed	Expected an Average of Twice Per Year	Observed	Expected an Average of Twice Per Year	Observed	Expected an Average of Twice Per Year	Maximum Observed	Maximum Observed
Individual Households, USDA & GE Data	2.0	2.4	0.4	0.7	11-17	13	2.0	4.0	22-24	31-46
Groups of Three Houses, USDA Data	1.5	1.9	0.7	0.8	5.8	7.9	2.0	2.8	-	-
Group of Six Houses, USDA Data	1.2	1.5	0.9	0.9	3.9	5.5	2.0	2.6	-	-

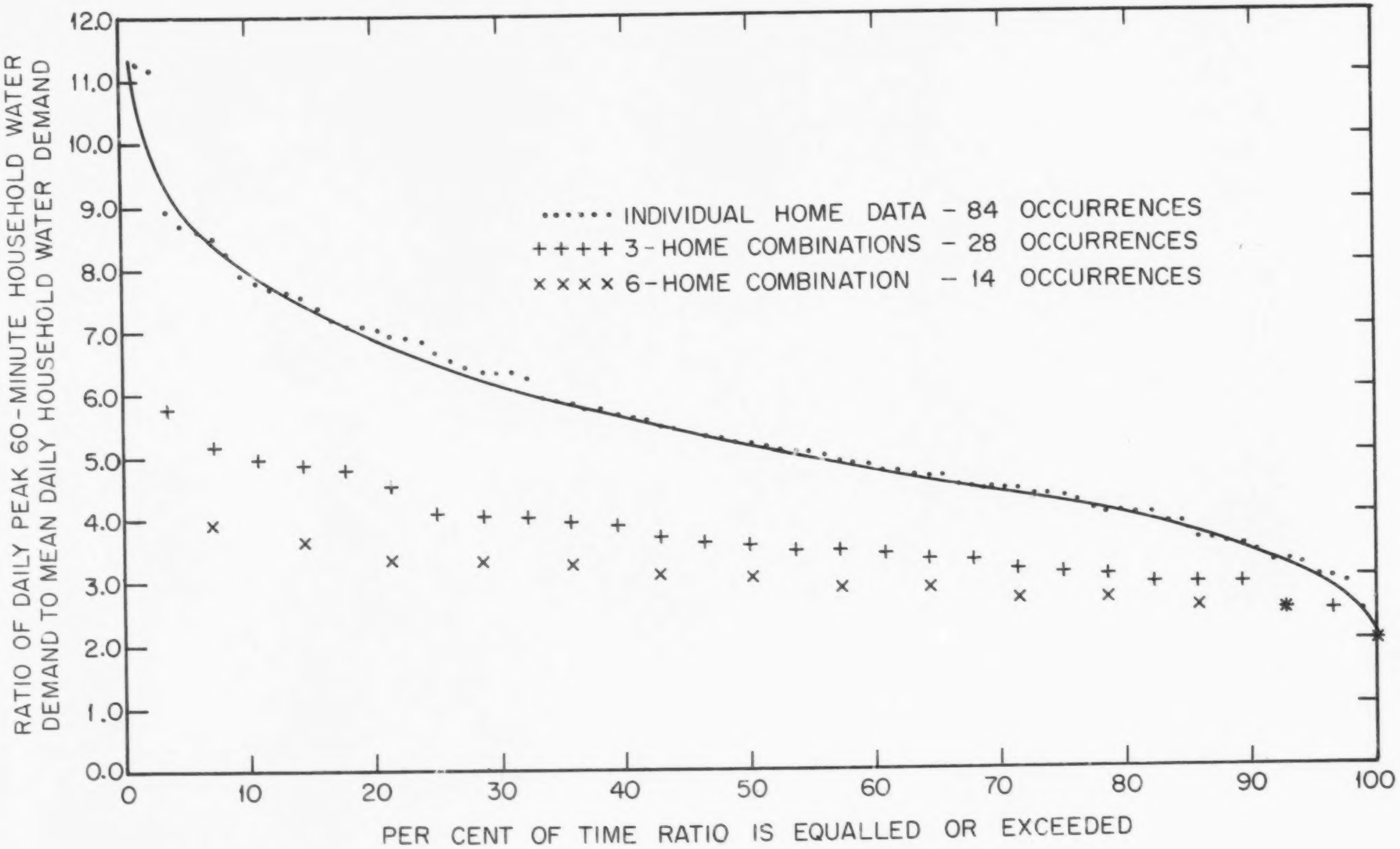


FIGURE 5

VARIATION IN PEAK HOUR WATER USE, COMBINATION OF SOURCES

(Reproduced from Fig. 3, Ref. 2)

A typical or representative day of water usage data for one home was selected. Average annual energy for pumping and grinding by a household storage-grinder-pump (SGP) unit was estimated using this data sample. The mass curve of inflow for the 24 hours of the selected typical day is shown in Fig. 6 together with that for a critical day that would place a severe loading on an SGP unit.

Combinations of storage volumes ranging from 20 to 30 gallons and pump capacities from 6 to 10 gallons per minute (gpm) were tested for adequacy against the most severe usage record, Fig. 6. Specifications thereby tentatively selected for a household unit were a 10 gpm nominal pumping rate and a storage of 30 gallons (Ref. 2). As the result of later studies (Ref. 9) this nominal pumping rate specification was increased to 12 gpm with 30 gallons of storage, and the unit finally developed by the General Electric Company (Section V) had a usable capacity range of 11 to 15 gpm with a tank of 44 gallons effective volume, a more desirable combination than the minimum capability sought.

Flow Rates in Collection System

The design of pressure laterals and smaller branch pressure sewers can be based on an analysis of cumulative rates from individual household units if suitable allowances are made for differences in time of outflow from the individual units and time of flow from the sources to the outlet. Outflows from storage-grinder-pump units for a group of six households were routed through street sewers using as inflows the peak demand day of the USDA data. Applying the principle of superposition, routed flows summed over time at the outlet point of a hypothetical pressurized lateral sewer serving six houses resulted in the following values:

	Gallons	Gallons per Minute
Maximum rate	--	20
4-minute peak volume and rate	60	15
15-minute peak volume and rate	120	8
60-minute peak volume and rate	330	5½

Each household unit was assumed to have a constant pumping rate of 10 gpm, or a combined capacity for the six units of 60 gpm. In contrast, above, the maximum rate at the outlet point was only 20 gpm. The attenuation of peaks diminished with increase in duration, becoming imperceptible for the 60-minute peak.

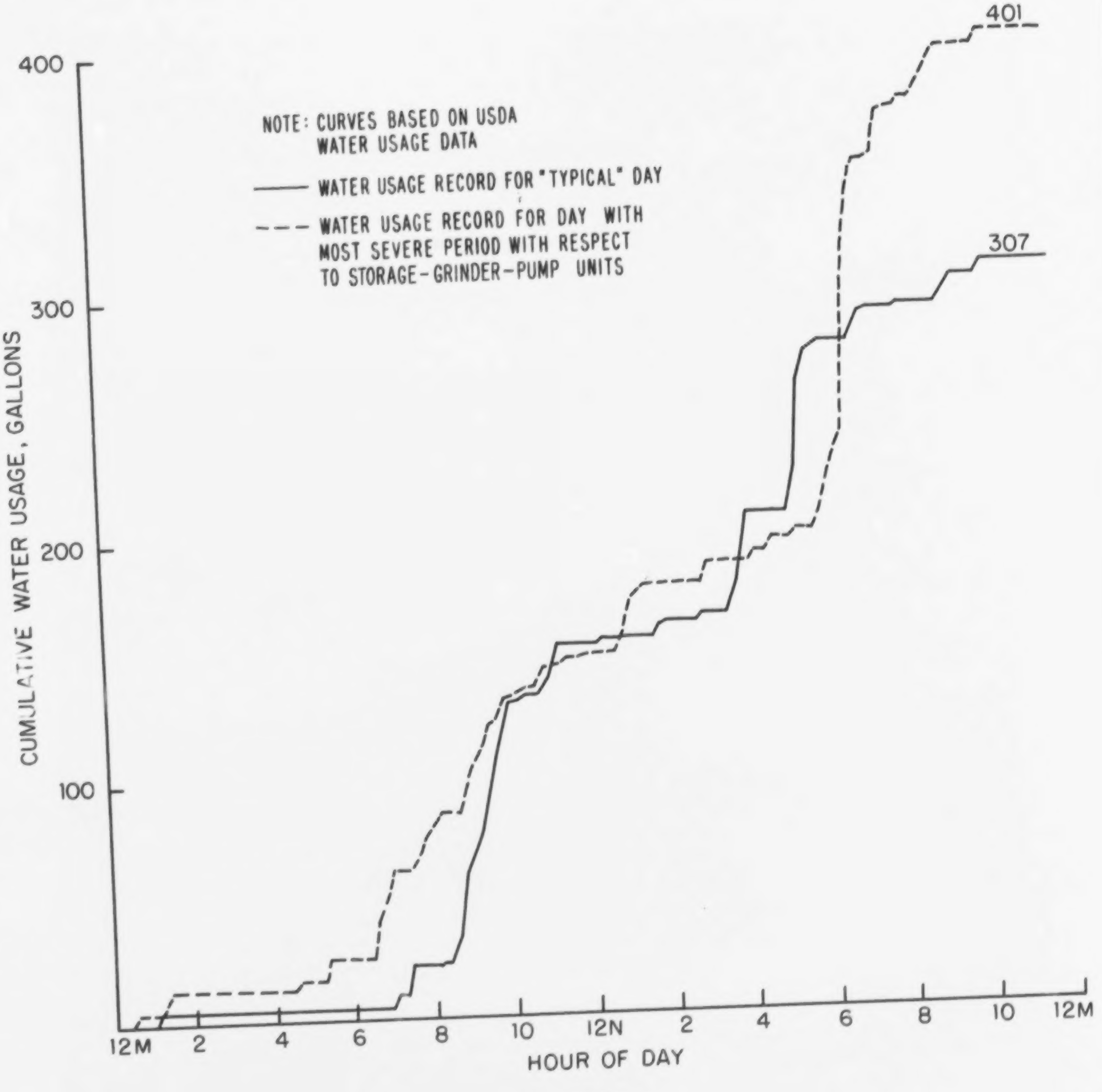


FIGURE 6
MASS CURVES OF WATER USAGE, SINGLE HOME

Comparison of Per Capita Flows with Flows Based on Water Demand Ratios

Per capita water discharges were determined from an analysis of Taft Center and Johns Hopkins University reports and are presented in Table 2.

Assuming that the results are reasonably representative of prevailing demand variations in different communities, estimated mean winter water demands for up to 500 homes and estimated winter per capita demands in terms of number of occupants per home may be in error by ± 30%. To be noted is that the entries in Table 2 are themselves averages of a number of observations and thus obscure further variations for individual homes and for year to year changes. For Santa Clara, California, (Ref. 30), the following results were obtained:

No. Occupants	Item	Jan.	Feb.	Mar.
3	No. of Home-Months	35	35	35
	Mean Use, gpcd	52	54	63
	Standard Deviation, gpcd	20	17	30
5	No. of Home-Months	31	32	32
	Mean Use, gpcd	41	44	45
	Standard Deviation, gpcd	24	14	15

Changes in building occupancy over the projected design period of sewer systems can be anticipated only subjectively. Mean annual domestic demands might be projected with a reasonable degree of confidence for expected future land-use, but the projections could be made realistically only for whole blocks or sub-areas in a given system. Hence, it is reasonable to conclude (1) that refinements in projections to account for differences in demand related to expected numbers of occupants per home would not be realistic, (2) that estimates of mean annual domestic demands based on data from other communities would contain considerable errors, and (3) that projection of such mean annual domestic demands to the end of the design period would require acceptance of rather specious criteria. Instead, it would appear preferable to project observed mean annual domestic demands for the drainage area of the system to be analysed, with the details available governing the attainable degree of refinement. If the sewer system is served by a fully metered water system and meter readings are suitable for direct use, acceptable estimates of mean annual sanitary sewage flows can be obtained by employing water-demand meter-readings for non-lawn-sprinkling months. Even though these may be fairly reliable indicators of present sewage flows, their projection will be subjective, and use of refinements, such as allowances for differences in the number of occupants per dwelling, does not appear to be justified.

TABLE 2

WINTER WATER DEMAND
(Reproduced from Table 1, Ref. 8)

	Taft Center Report							Johns Hopkins	
Month*	J-F-M	J-F-M	J-F-M	J-F-M	J-F-M	J-F-M	Winter	Winter	Fit, Five Areas (Md.)
State (County)	N.J. (Bergen)	Texas (Dallas)	Tenn. (Knox)	Calif. (Santa Clara)	N.C. (Mecklenberg)	Texas (Nueces)	Ten Areas	Pine Valley (Md.)	
2 persons									
gpd	83	180	102	81	120	178	142	70	
gpcd	42	90	51	40	60	89	71		(80)
gpcd**	(61)	(100)	(54)	(60)	(62)	(74)	(71)		
3 persons									
gpd	158	251	133	169	149	186	178	72	
gpcd	53	84	44	56	30	62	59		(61)
gpcd**	(52)	(81)	(44)	(54)	(49)	(54)	(60)		
4 persons									
gpd	210	286	152	228	172	201	232	52	
gpcd	53	72	38	57	43	50	58		(51)
gpcd**	(48)	(71)	(39)	(50)	(43)	(44)	(55)		
5 persons									
gpd	210	314	169	216	200	218	262	39	
gpcd	42	63	34	43	40	44	66		(44)
gpcd**	(45)	(65)	(36)	(48)	(39)	(38)	(51)		
6 persons									
gpd	278	348	191	304	217	234	292	-	
gpcd	46	58	32	51	36	39	49		(39)
gpcd**	(44)	(61)	(33)	(47)	(37)	(34)	(49)		
Total No. Homes:	97	495	90	21	207	56	21-495	120	
Total Record:	1955-60	1955-59	1947-58	1949-57	1950-58	1948-53	Varies	1959-62	Varies

* : J-F-M = January, February and March.
**: From statistical fits to data by Taft Center.

It was assumed for the ASCE Project that presentation and usage of data on residential demand variability from diverse communities should preferably be in terms of variations about their respective winter average domestic water demands.

Design Curves

Based (1) on data in a Johns Hopkins University report (Ref. 32) for cities in the northeastern quadrant of the continental United States and northern California and (2) on the data discussed earlier in this section, curves for Northeastern United States and California were derived from Tables 3 and 4 and are presented in Figs. 7 and 8. These curves were used in the preliminary design of pressure sewers in studies of hypothetical combined-sewer separation systems in two cities (Section IX). (For further discussion of the application of these curves see Section VII and Ref. 8).

USDA data (Ref. 2) for individual household winter water demands were utilized as inflows to various sized tributary portions of the hypothetical pressure sewer system for the Milwaukee Study Area (Ref. 17) in an exploratory wastewater routing study (Ref. 14). The results indicate: that the rate of attenuation with number of dwelling units of the upper curve in Fig. 7 is reasonably realistic; and that although this curve was drawn as an envelope of the available data it lies definitely below a comparable curve for peaks of a few minutes duration obtained from the routing study, and its use for determining expected maximum hydraulic gradients in the Milwaukee Study Area system was therefore not particularly conservative.

Flows from Commercial Buildings

There is little information other than that in Refs. 18 and 33 on flows from commercial buildings, such as hotels and restaurants. The Commercial Water Use Research Project, (Ref. 33), provides some data on flows from individual buildings for 42 business establishments in Baltimore. However, there would be considerable difficulty in integrating this information into the use of Figs. 7 and 8 for areas of mixed residential and commercial development.

Design ratios for peak hour demands proposed in the Commercial Water Use Report are as follows:

TABLE 3

NORTHEASTERN U.S. VARIATIONS IN DOMESTIC WATER DEMAND

(Reproduced from Table 2, Ref. 8)

		Winter Rates (Dec., Jan. and Feb.)									
		Gal./Day/Dwelling Unit					Ratios				
Northeastern U.S., Location/Area	No. of Dwelling Units	(a) Avg. Annual	(b) Min. Daily	(c) Max. Daily	(d) Peak Hourly	(e) Peak Hr. of Min. Day	(b) ÷ (a)	(c) ÷ (a)	(d) ÷ (a)	(e) ÷ (a)	No. Full Days of Data
Des Moines, Ia.											
Patricia Park	325	182	(167)	242	425	(354)	(0.92)	1.33	2.34	(1.95)	106
Clive	307	165	(162)	195	405	(275)	(0.98)	1.18	2.45	(1.67)	33
Wash. Sub. San Dist.											
Palmer Park	395	175	(171)	219	431	(273)	(0.98)	1.25	2.46	(1.56)	13
Glenmont	129	173	(176)	216	409	(298)	(1.01)	1.25	2.36	(1.72)	11
English Manor	309	224	(190)	276	536	(482)	(0.85)	1.23	2.39	(2.15)	28
N.W. Branch Est.	124	262	(274)	290	542	(542)	(1.04)	1.11	2.07	(2.05)	2
Baltimore, Md.											
Country Club Park	289	189	(154)	243	442	(367)	(0.82)	1.29	2.34	(1.94)	39
Pine Valley	210	204	(148)	272	555	(326)	(0.73)	1.33	2.72	(1.59)	225
Campus Hills	179	251	(249)	323	602	(471)	(0.99)	1.29	2.40	(1.87)	163
Hampton	44	157	(133)	216	457	(277)	(0.85)	1.38	2.91	(1.76)	90
Philadelphia, Pa.											
Normandy	410	220	(262)	331	595	(407)	(1.19)	1.50	2.70	(1.85)	53
Benton St.	200	252	(182)	303	565	(413)	(0.72)	1.20	2.24	(1.64)	32
Phila. Suburban											
Downeast	287	212	—	262	477	—	—	1.24	2.25	—	(0)
St. Albans	137	195	(166)	242	596	(356)	(0.85)	1.24	3.06	(1.82)	44
Dogwood Lane	113	228	(188)	322	713	(380)	(0.82)	1.41	3.13	(1.66)	131
English Manor-U.S.D.A.	(1)						0.40	2.40	13.0	2.0	—
(From Ref. 2)	(3)						0.70	1.85	7.9	2.0	—
	(6)						0.87	1.45	5.5	2.0	—

TABLE 4

CALIFORNIA VARIATIONS IN DOMESTIC WATER DEMAND
(Reproduced from Table 3, Ref. 8)

California, Location/Area	No. of Dwelling Units	Winter Rates (Dec., Jan. and Feb.)									No. Full Days of Data
		Gal./Day/Dwelling Unit					Ratios				
		(a) Avg. Annual	(b) Min. Daily	(c) Max. Daily	(d) Peak Hourly	(e) Peak Hr. of Min. Day	(b) ÷ (a)	(c) ÷ (a)	(d) ÷ (a)	(e) ÷ (a)	
East Bay											
San Lorenzo	81	233	(210)	452	1227	(386)	(0.90)	1.94	5.27	(1.66)	180
Creekside Acres	143	295	(214)	610	1635	(377)	(0.73)	2.07	5.54	(1.28)	151
Burton Valley	137	282	(269)	474	1242	(559)	(0.96)	1.68	4.40	(1.98)	88
Chabot Park	295	297	(253)	700	1665	(562)	(0.85)	2.36	5.61	(1.89)	76
San Diego											
Rancho Hills	112	215	(176)	294	705	(337)	(0.82)	1.37	3.28	(1.57)	151
R.H. Sewage	(110)	(239)	(135)	(376)	(754)	(273)	(0.59)	(1.64)	(3.28)	(1.19)	171
Ruffin Road	259	234	(199)	377	1338	(374)	(0.85)	1.61	5.72	(1.62)	75
Muirlands	66	344	(265)	598	1547	(558)	(0.77)	1.74	4.50	(1.62)	168
Muir. Sewage	(71)	(336)	(243)	(467)	(846)	(549)	(0.72)	(1.39)	(2.52)	(1.64)	80
Helix Irrig. Dist.											
El Cajon	187	194	(177)	322	912	(317)	(0.91)	1.66	4.70	(1.63)	35
Lemon Grove	235	223	(173)	379	924	(374)	(0.78)	1.70	4.14	(1.68)	166
Cal. Water and Tel.											
Minot Ave	63	150	(126)	335	940	(256)	(0.84)	2.23	6.27	(1.71)	77
Sacramento											
Golf Course Terr.	134	248	(285)	559	1090	(479)	(1.15)	2.25	4.40	(1.93)	15

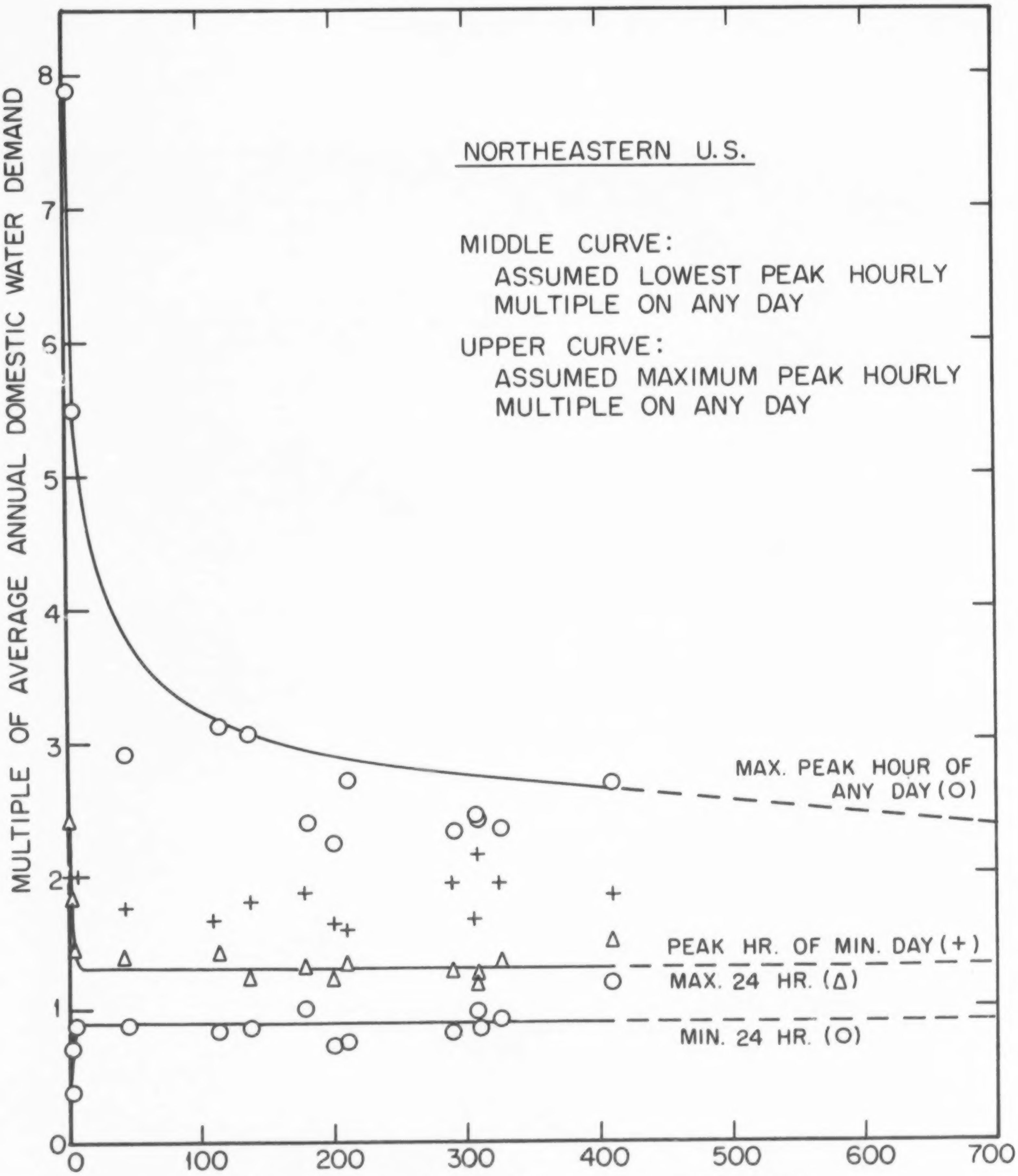


FIGURE 7
WATER DEMAND VARIATIONS, NORTHEASTERN U.S.
(Reproduced from Fig. 1, Ref. 8)

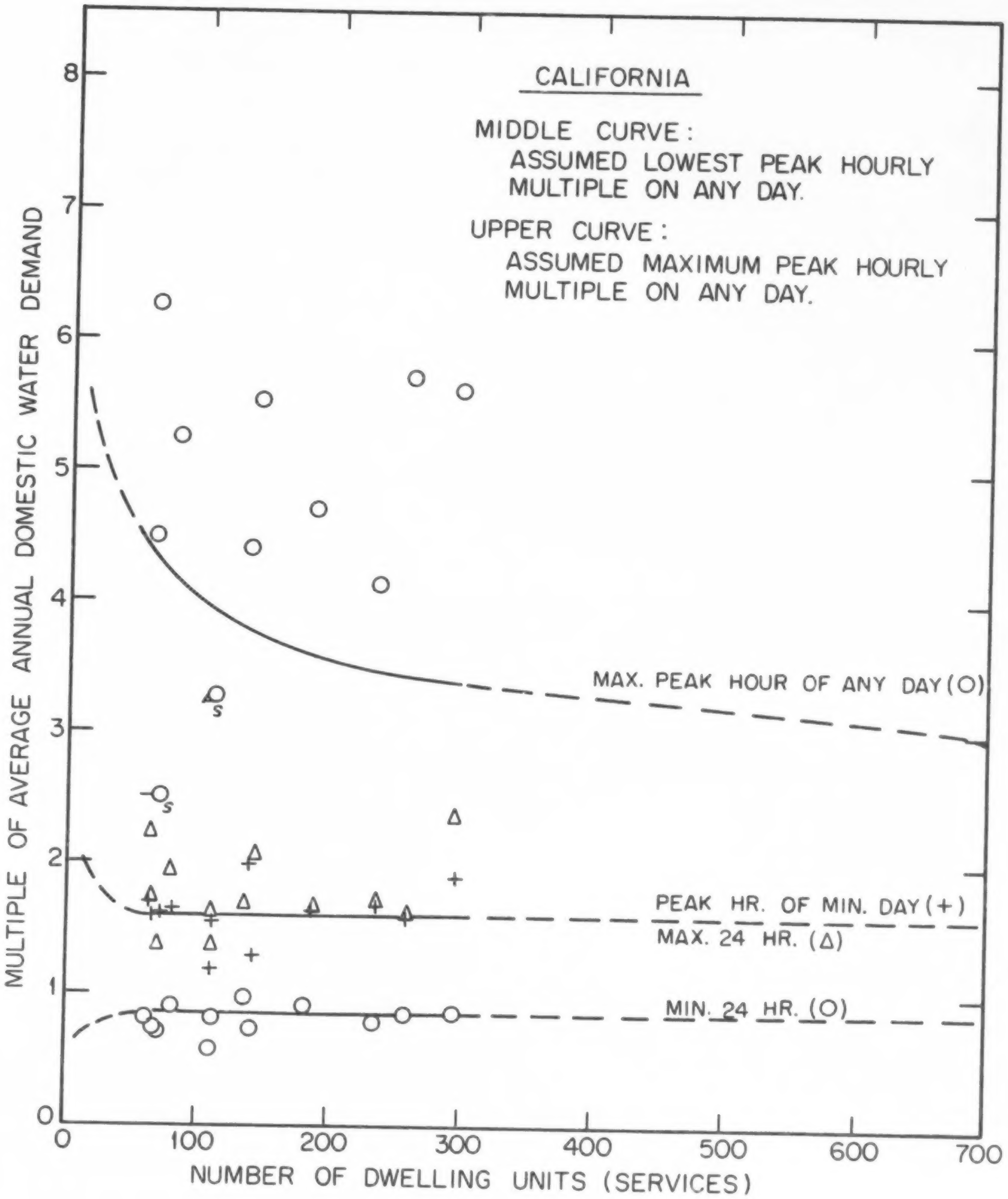


FIGURE 8
WATER DEMAND VARIATIONS, CALIFORNIA
(Reproduced from Fig. 2, Ref. 8)

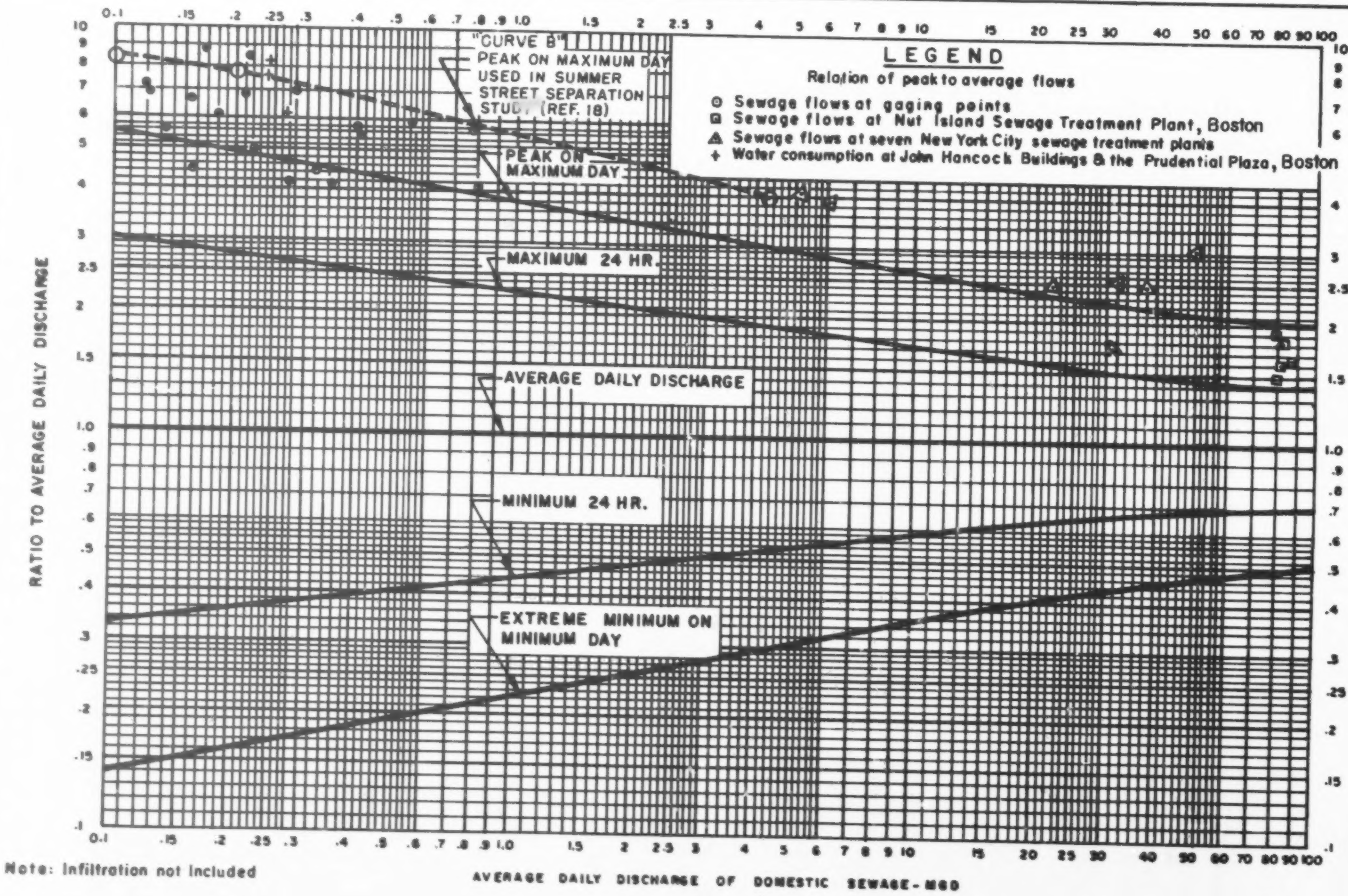
Type of Establishment or Institution	Ratio of Peak-Hour to Annual Water Use
High-rise apartments	2.6
Office buildings, general offices less than 10 yr. old	3.6
Department stores	2.9
Commercial laundries and dry cleaners	3.1
Conventional restaurants	3.6
Barber shops	4.4
Beauty salons	2.5

Compared with the upper curve of Fig. 7 for groups of homes, most of these ratios are not particularly high. In a study of demands for a hypothetical community of 100,000 persons with 28,000 dwellings, synthesized from demand hydrographs in the Commercial Water Use Report, including those for a representative number of institutions and commercial establishments, the commercial demands for a typical winter day (no lawn sprinkling) during the peak hour constituted only a fifth of the total demands. Presumably the same relative magnitude would be maintained approximately also for the peak hour of a year, provided lawn sprinkling is discounted.

A copy of Fig. III-1 from Ref. 18, "Relation of Extreme Discharges on Maximum and Minimum Days to the Average Daily Discharge of Domestic Sewage," similar to Fig. 5 in Ref. 34, is presented as Fig. 9 together with Curve B from Fig. III-7 of Ref. 18, "Peak on Maximum Day" which was used in the Summer Street Separation Study for Boston (Section IX). Fig. 9 is based on observed sewer flows, corrected for infiltration, and on water records, for municipalities and sectors of municipalities in New England with mean domestic sewage flows of about 0.1 mgd or greater. Fig. 7 does not include data for New England, Fig. 9 is for heterogeneous land-occupancy and not for household flows alone, and hence Fig. 9 rather than Fig. 7 was deemed appropriate for application to mixed-occupancy areas in New England and was used in a study of a hypothetical combined-sewer separation system in Boston (Section IX).

Comparison of Observed Sewage Discharges with Water Demands

Data on sewage flows from two household observation stations in Louisville, Kentucky were obtained for the ASCE project by the Water Management Laboratory of the General Electric Company. Discharges were



Note: Infiltration not Included

FIGURE 9
RELATION OF EXTREME DISCHARGES ON MAXIMUM AND MINIMUM DAYS TO THE AVERAGE DAILY DISCHARGE OF DOMESTIC SEWAGE (Reproduced from Fig. III-1 of Ref. 18)

measured at the individual pump installations by observing displacement in the wet well and length of operation of the constant discharge pump. Allowances were made for periods during which flows were bypassed. The observations covered a period of about two months.

Comparisons of sewage discharged with water supplied, due allowance being made for storage in the system and the pump wet well, agree closely, indicating that water demand rates can be safely substituted for rates of sewage outflow.

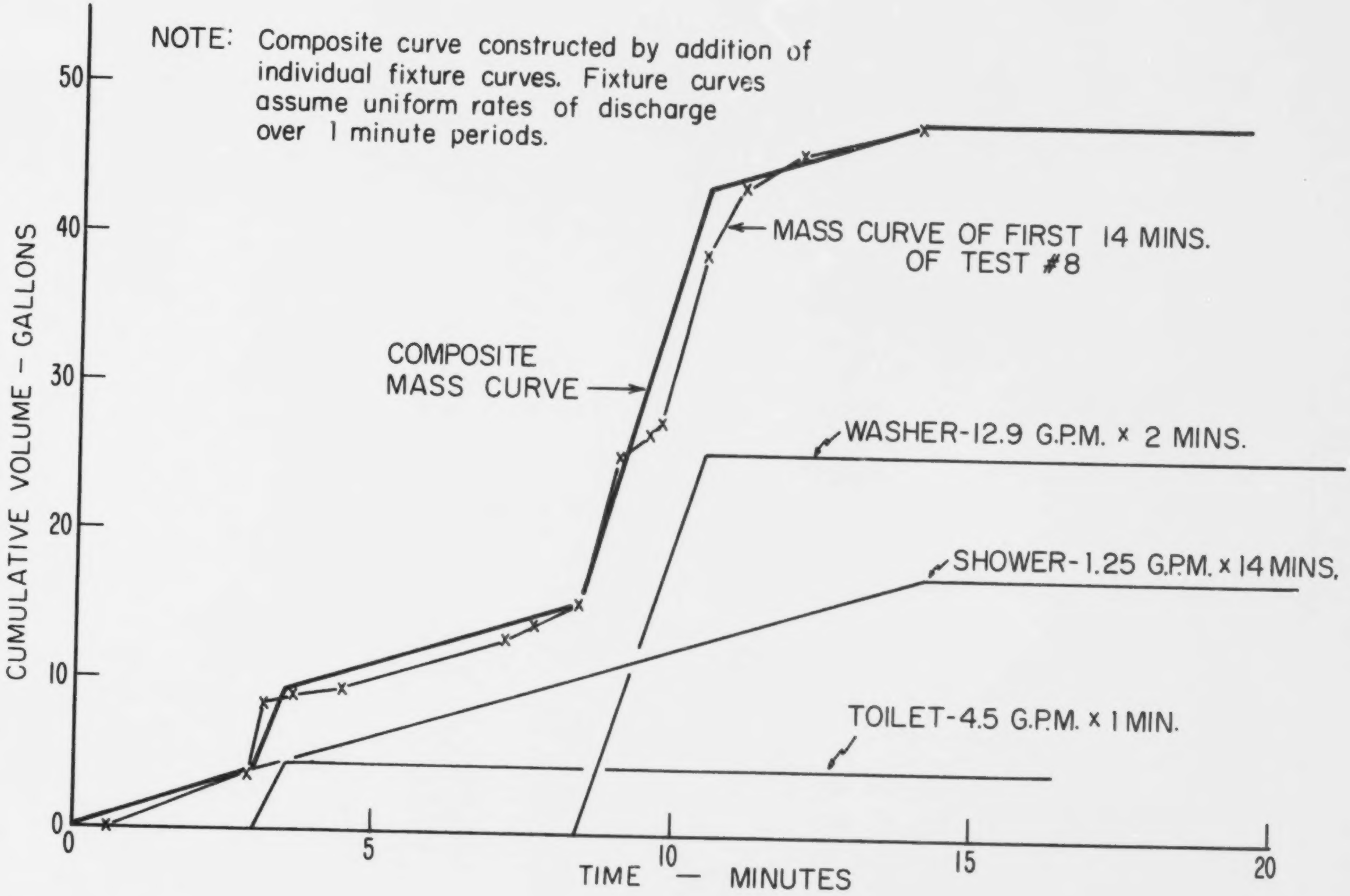
Unit Fixture Discharge Rates

The ASCE Project staff studied unit fixture discharge rates obtained from the G.E., Louisville data (Ref. 19), in order to synthesize composite hydrographs for refinement of pump capacities and associated storage requirements. Fig. 10 shows a composite hydrograph based on superposition of component 1-minute flows in comparison with a mass curve of observed flows for fixtures including a toilet, a shower, and a washing machine. The synthesized composite discharge pattern appears to represent reasonably the household sewage discharge, and it seems that the method of superposition of flows can be applied safely.

Table 5 indicates the volumes of storage used in a storage-pump-grinder unit for synthesized hydrographs of flow from three combinations of fixtures and a constant pump discharge of 13 gallons per minute (gpm). The fixture combinations are as follows:

Combination	Fixtures included
I	Toilet, washbasin, bathtub, kitchen sink, dishwasher, and clothes washer
II	Same as I, plus a second toilet and washbasin
III	Same as II, plus a third toilet and washbasin.

Table 5 shows that storage capacity needed to accommodate flows from the assumed combinations of fixtures is determined by sewage flows that would occur during the first three minutes or so of the maximum flow period. According to similar synthetic hydrograph calculations, for pump capacities of 10 and 15 gpm, 26 and 18 gallons respectively would have to be stored to accommodate the simultaneous flow of about 46 gallons in a 2-minute period from a bathtub and an automatic clothes washer. The probability of simultaneous discharge of fixtures of this kind is high.



NOTE: Composite curve constructed by addition of individual fixture curves. Fixture curves assume uniform rates of discharge over 1 minute periods.

FIGURE 10
COMPARISON OF DISCHARGE FROM FIRST PART OF TEST #8, STATION A, WITH COMPOSITE DISCHARGE CURVE (DATA FROM REFS. 9 AND 19).
(Reproduced from Fig. 17, Ref. 9)

TABLE 5

DETERMINATION OF STORAGE, FOR SYNTHETIC HYDROGRAPHS, PUMP DISCHARGE RATE OF 13 GPM

(Reproduced from Table 16, Ref. 9)

Volume, Gallons

Time (minutes):	1	2	3	4	5	6	7	8	9	10	11	12	13
Combination I inflow	45.5	14	5	8.5	5	1	10.5	3	5	6.5	5	1	10.5
Into storage, inflow less pump discharge	32.5	1	-8	-4.5	-8	-12	-2.5	-10	-8	-6.5	-8	-12	-2.5
Total in storage	32.5	33.5*	25.5	21	13	1	---	---	---	---	---	---	---
			(* Maximum Storage Used - 33.5 gallons)										
Combination II inflow	50.5	15	10	9.5	10	2	15.5	4	10	7.5	10	2	15.5
Into storage, inflow less pump discharge	37.5	2	-3	-3.5	-3	-11	2.5	-9	-3	-5.5	-3	-11	2.5
Total in storage	37.5	39.5*	36.5	33	30	19	21.5	12.5	9.5	5	1	---	2.5
			(* Maximum Storage Used - 39.5 gallons)										
Combination III inflow	55.5	16	15	10.5	15	3	20.5	5	15	8.5	15	3	20.5
Into storage, inflow less pump discharge	42.5	3	2	-2.5	2	-10	7.5	-8	2	-4.5	2	-10	7.5
Total in storage	42.5	45.5	47.5*	45	47	37	44.5	36.5	38.5	34	36	26	33.5
					(* Maximum Storage Used - 47.5 gallons)								

Storage Volume and Minimum Required Pump Rate

Table 6 lists the rates of fixture discharge and synthesized rates of flow for Combinations I, II, and III and Table 7 gives the storage volumes computed for the three synthesized household loading conditions for pumping rates from 8½ to 16 gpm. The relation between required storage and pump capacity for the synthesized inflow sequences is shown in Fig. 11.

The storage volumes and minimum pump discharge rates in Fig. 11 should be considered extreme upper limits. Underlying frequencies, durations, and rates of fixture use are deliberately conservative. The only ordinary discharges that the given storage volumes are not designed to accommodate are those of the second bathtub in a two-bathroom house or those of the second and third bathtubs in a three-bathroom house during the first 5 minutes of the maximum discharge period. Storage requirements for Combinations II and III are not affected by the discharge of one extra bathtub after 6 minutes or more from the beginning of the maximum flow period. However, the associated available storage at the end of the maximum discharge period is significantly reduced. The hydrographs do not include flows caused by extraordinary discharges of fixtures such as (1) leakage from a defective toilet-tank outlet-valve assembly, and (2) discharge of a hose into a basement floor drain. The possibility of such flows during a period of maximum discharge is discounted because a toilet discharging in this manner would not operate also as asuumed in the fixture combinations; and because the occupants of a house containing a storage-pump combination would presumably be aware of the need to exercise some control over extraordinary discharges.

Suggested Measurements

Future tests should include the measurement of flows from individual households, groups of households served by single laterals, and pressure sewers in districts serving many contributors. The measurements should be made in as much detail as possible, in order to serve as sources of information for the modification of design data. The characteristics of sewage entering and discharged from the pressure system should be determined to ascertain the effect of the system on the sewage discharged to the intercepting sewer system for treatment, permitting further refinement of pressure-sewer design.

TABLE 6

MEAN RATES OF DISCHARGE OF INDIVIDUAL FIXTURES AND SYNTHETIC "MINIMUM" DISCHARGE RATES FOR FIXTURE COMBINATIONS

(Reproduced from Table 17, Ref. 9)

Fixture or Combination	Rate GPM	Duration minutes	Frequency minutes	Mean Discharge GPM
Toilet	5	1	2	2.5
Basin	1	1	2	0.5
Bathtub	20	1	15	1.3
Sink	5.5	1	3	1.8
Clothes Washer	13	2	13	2.0
Dishwasher	12	over	33 mins.	0.4
Combination I	--	--	--	8.4
Combination II	--	--	--	11.4
Combination III	--	--	--	14.4

TABLE 7

SYNTHESIZED STORAGE-PUMP COMBINATIONS

(Reproduced from Table 18, Ref. 9)

	Storage Volume in Gallons for Given Pump Discharge Rate					
Pump Discharge Rate (GPM):	8.5	10	11.5	13	14.5	16
1 Bathroom House	42.5	39.5	36.5	33.5	31.0	29.5
1½ or 2 Bathroom House	--	--	42.5	39.5	36.5	34.5
2½ or 3 Bathroom House	--	--	--	--	43	39.5

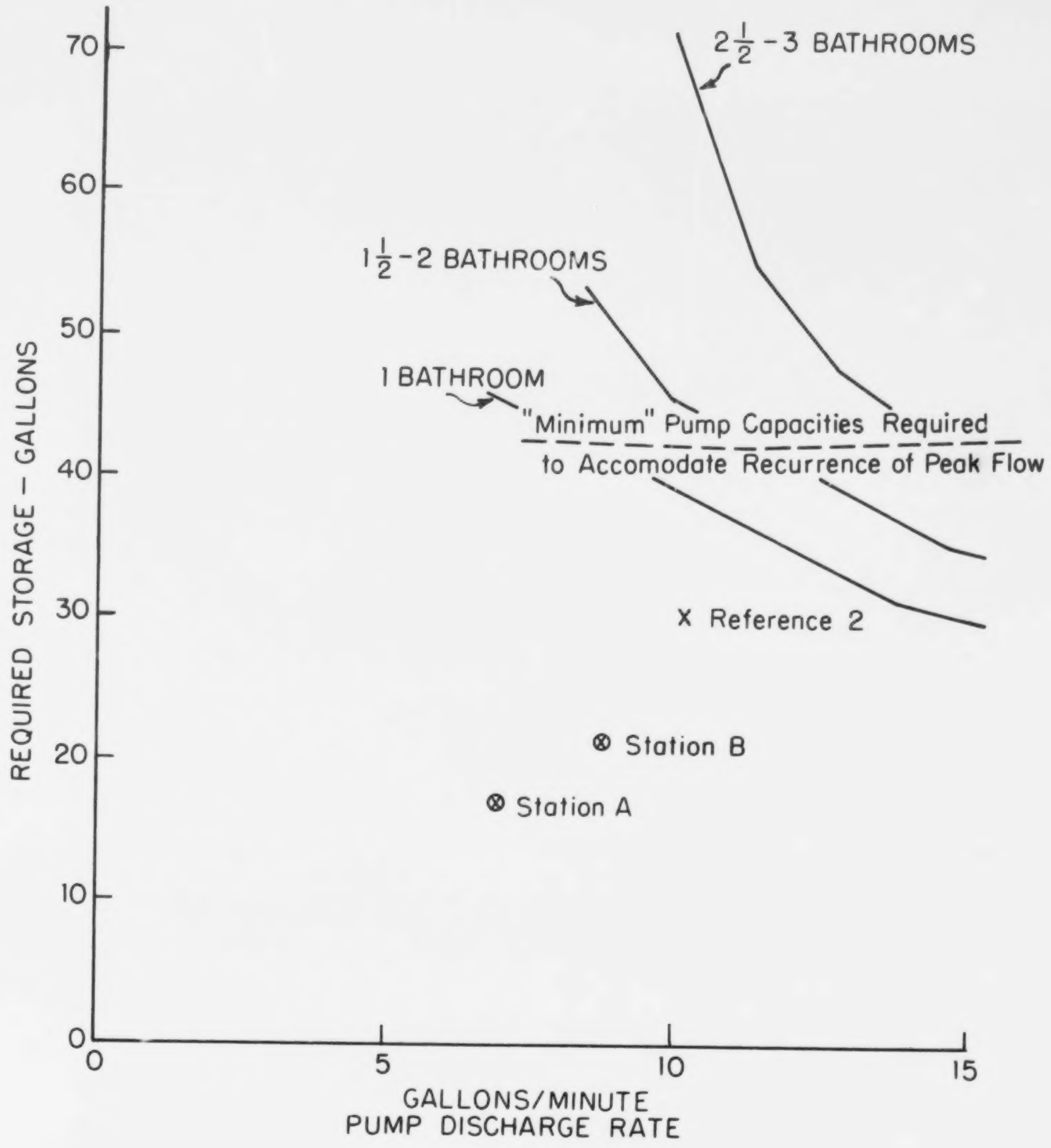


FIGURE 11
STORAGE-PUMP COMBINATIONS TO ACCOMMODATE SYNTHETIC INFLOWS
(Reproduced from Fig. 21, Ref. 9)

SECTION V

EQUIPMENT FOR STORING, GRINDING AND PUMPING SEWAGE FROM RESIDENTIAL AND OTHER SMALL SOURCES*

Introduction

A prototype of the storage-grinder-pump household unit (SGP) was developed in 1967-1968 by the Research and Development Center of the General Electric Company, at Schenectady, N.Y. under subcontract with ASCE as part of the Combined Sewer Separation Project.

Performance Requirements

Initial requirements, modified somewhat during the period of development, were based on: experience with mock-up units at observation stations at two households in Louisville, Ky., Refs. 19 and 20; and research reported by the ASCE Project staff, especially Refs. 2, 6, 8 and 9. The established requirements follow.

For a storage-grinder-pump unit serving a single residence, the probable required effective volume of the receiving tank lies between 30 and 45 gallons and the pump discharge rate between 10 and 15 gallons per minute (gpm), as is explained in the previous section.

The target range of pump discharge head was 0 to 35 pounds per square inch above atmospheric pressure (psig). In order to maintain pressurization of the sewerage system at all times, the minimum curb pressure criterion was set at 0 psi, requiring a typical minimum SGP unit discharge pressure of approximately 0 to 5 psig. The maximum economical curb pressure was initially assumed to be 30 psi, requiring a typical maximum SGP unit discharge pressure of 30-35 psi.

The grinder should be capable of reducing solids introduced through household plumbing fixtures to sizes clearing the pump spaces, the check and pressure control valves, and the pressure tubing. Controls and mechanical equipment should be completely reliable, need little maintenance and repair, and be low in purchase price and cost of installation.

For household flows beyond the capacity of a single SGP unit, it was assumed that two or more units would be installed in parallel and provided with a larger discharge line to the pressure sewer in the street. As an alternative, an enlarged unit might be developed with a greater capacity if the 11 to 15-gpm prototype is found to work well in practice.

---

* Ref. 21.

The General Electric Household SGP Unit

The SGP unit developed by the General Electric Company is shown in a cut-away sketch in Fig. 12; and is pictured in Figs. 13, 14 and 15 (Figs. 1, 6 and 20 of Ref. 21). The characteristic curves of the progressing-cavity type pump (Moyno, Model FS-44, Robbins & Myers) are shown in Fig. 16 (Fig. 15 of Ref. 21), and dimensions of the reinforced concrete or steel receiving and storage tank are shown on Fig. 17 (Fig. 19 of Ref. 21). Specifications for the prototype storage-grinder-pump unit are given in Table 8 (Table 5 of Ref. 21).

The SGP unit functions as a grinder, pump, and backflow preventer in an integral assembly that can be installed in a receiving tank below the basement floor or otherwise in line with the house drain. The inlet connection attaches to standard 3-in. or 4-in. drain-waste-vent piping in the plumbing system. Discharge piping is 1¼-in. copper tubing connected to polyethylene or other acceptable tubing outside the foundation wall.

The single-phase electric wiring is designed to carry 230 volts and 10 amperes or 115 volts and 20 amperes at 60 Hz. The pump and grinder are driven by a 1 horsepower capacitor-start motor. The unit delivers between 11 and 15 gallons per minute of finely ground sewage slurry to the discharge tubing at pressures from zero to 35 psig. The effective storage of the tank is 44 gallons.

Backflow is prevented by a special check valve, designed for reliable operation in sewage containing ground solids such as bits of string and fabric, small blocks of wood, gritty substances and fruit rinds and pulps. The check valve has a low head-loss characteristic of about 0.8-in. Hg (0.4 psi) for flows between 10 and 13 gpm.

Equipment Installation and Operating Costs

The General Electric Company estimates that without the receiving tank the SGP unit can be manufactured in quantity at a wholesale price of between $309 and $412 and a most probable price of $343 (December, 1968 price level). The Company estimates the cost of the installed SGP unit, locally purchased receiving tank and plumbing and electrical labor based on prevailing price levels, at about $550 for new work and about $650 for work requiring cutting and remodeling of existing house drainage piping.

Operating costs of the SGP for a year, not including service charges for maintenance and repair or replacement of parts, are estimated by General Electric at $2 for energy costs of 1½-cents per K.W.H. and power consumption of about 1-kw for a family of five and an average sewage flow of 60 gallons per capita per day.

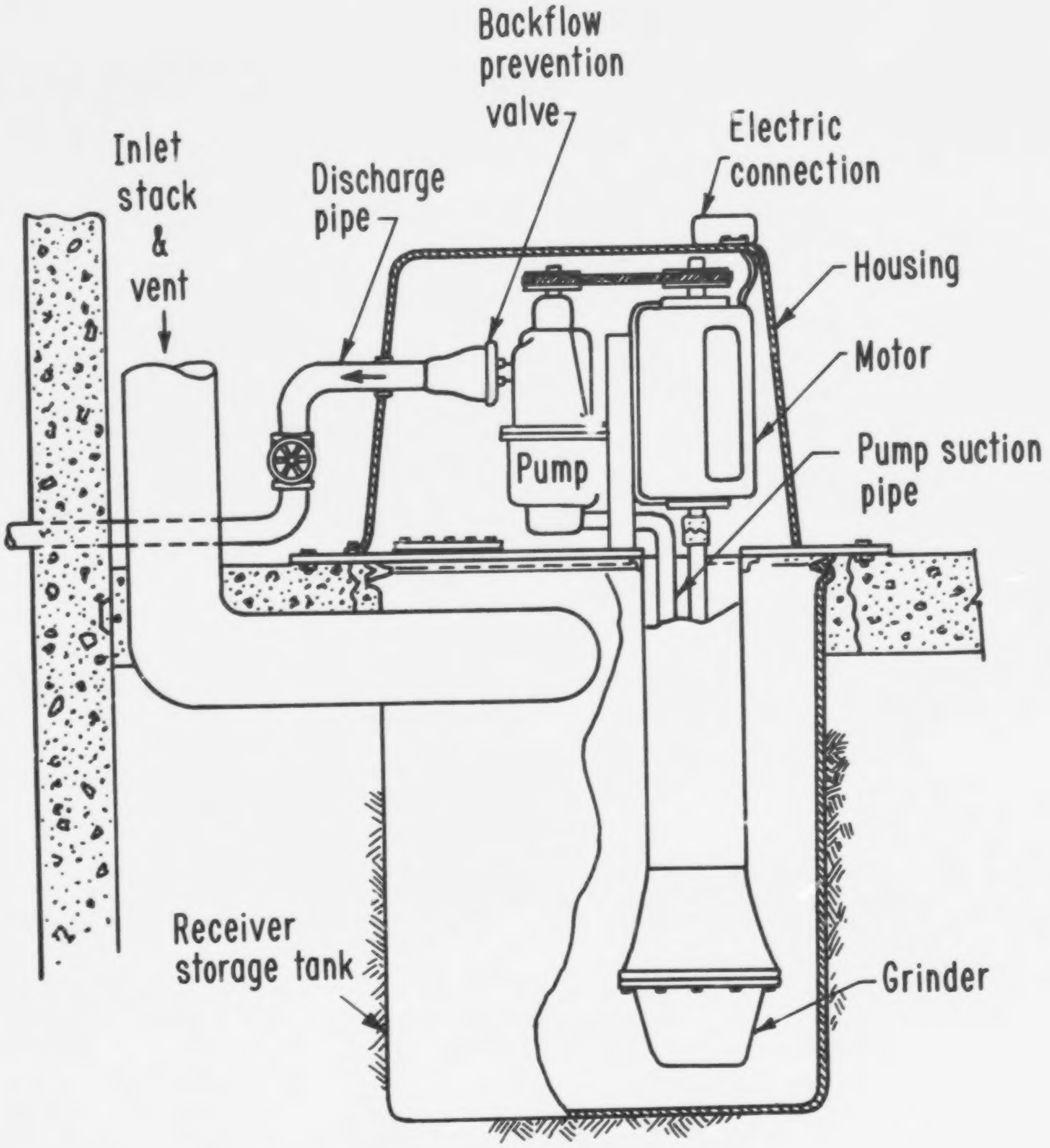


FIGURE 12
CUT-AWAY SKETCH OF HOUSEHOLD
STORAGE - GRINDER - PUMP UNIT
(Adapted from Fig. 5-1, Ref. 16)

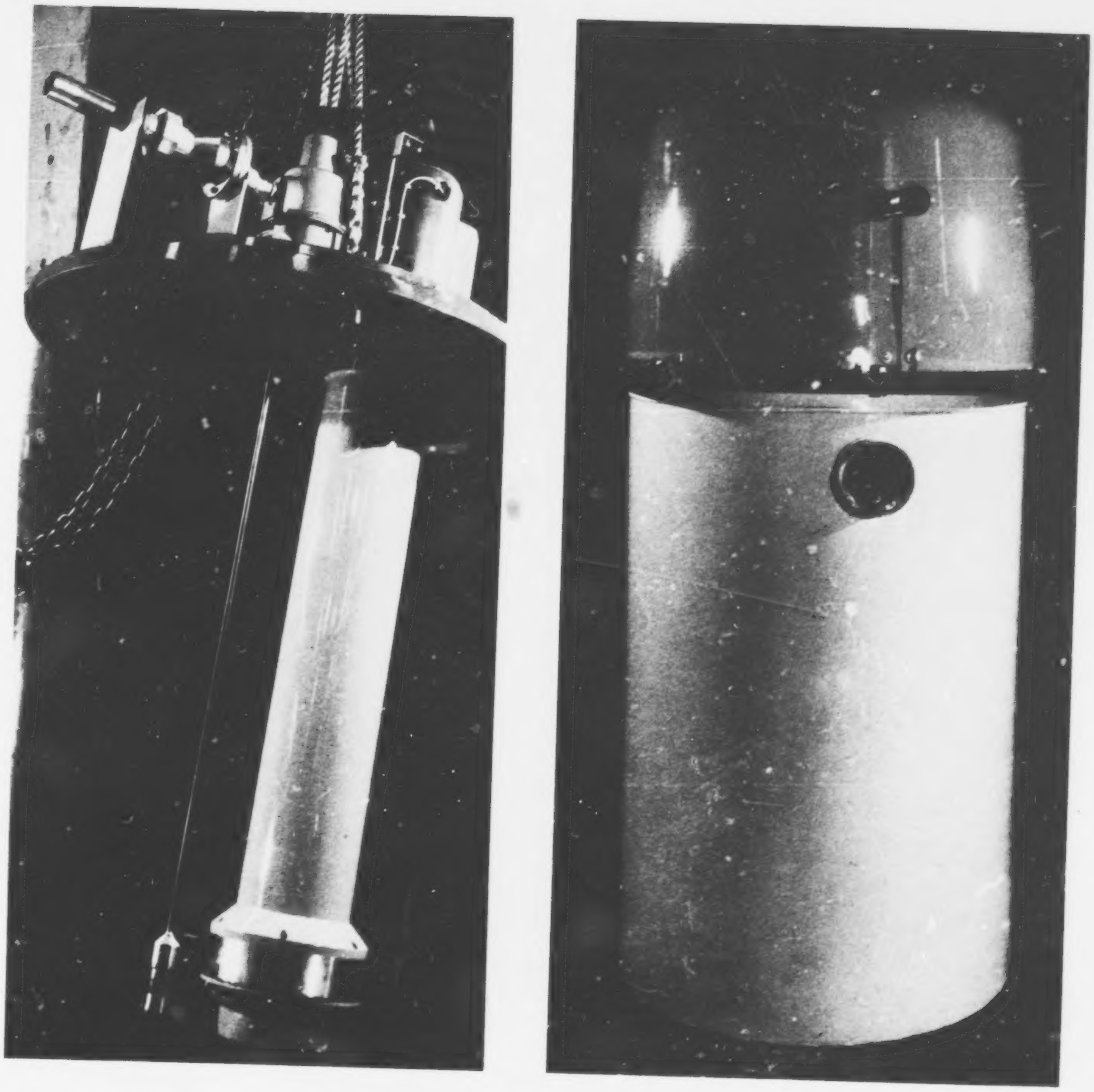


FIGURE 13
COMPLETED PROTOTYPE OF HOUSEHOLD
STORAGE-GRINDER-PUMP UNIT
(Reproduced from Fig. 1, Ref. 21)

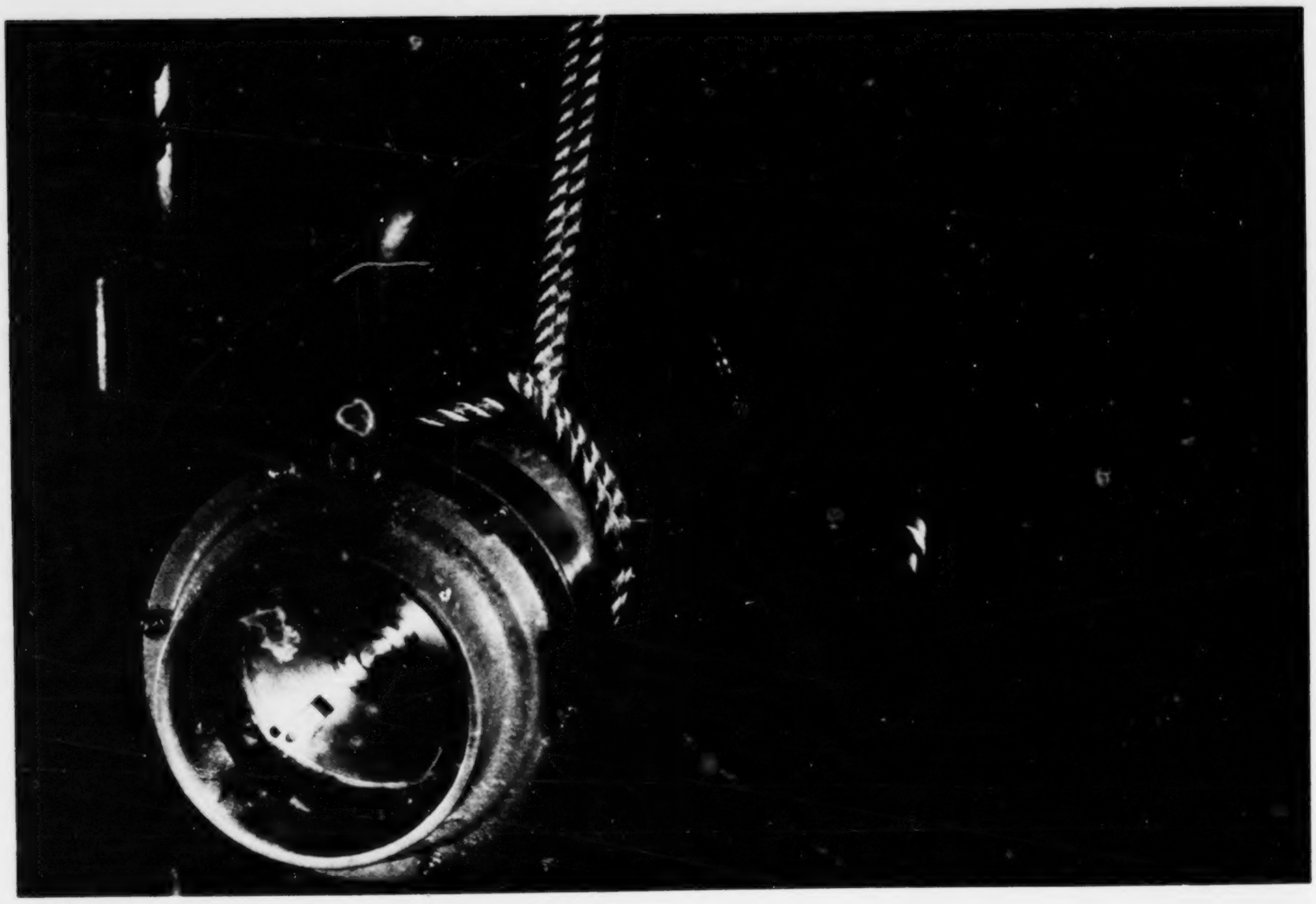


FIGURE 14
GRINDER MECHANISM VIEWED FROM
BELOW THROUGH PUMP SUCTION BELL
(Reproduced from Fig. 6, Ref. 21)

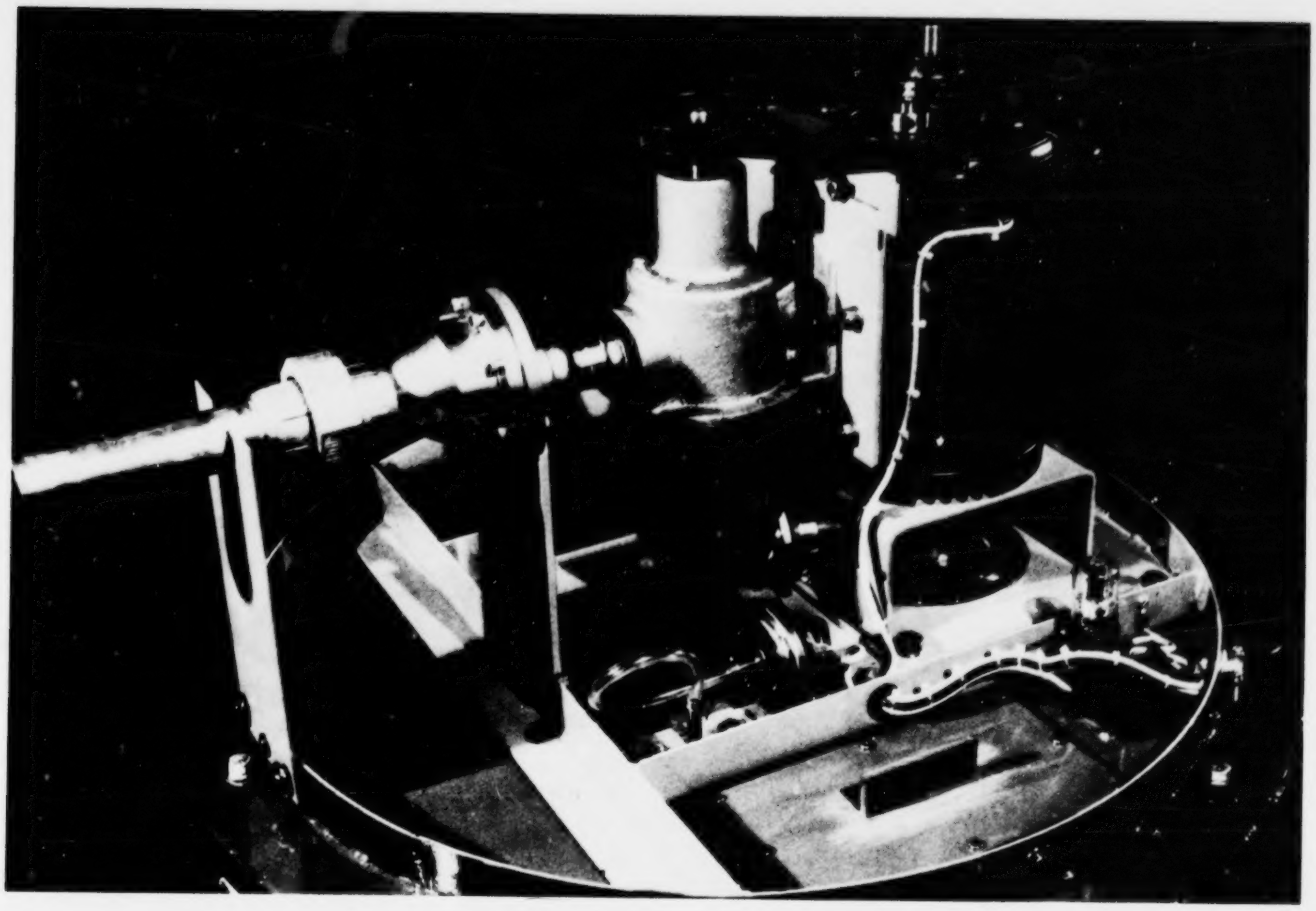


FIGURE 15
CLOSE-UP VIEW OF COMPONENTS
ABOVE MOUNTING FLANGE
(From Fig. 20, Ref. 21)

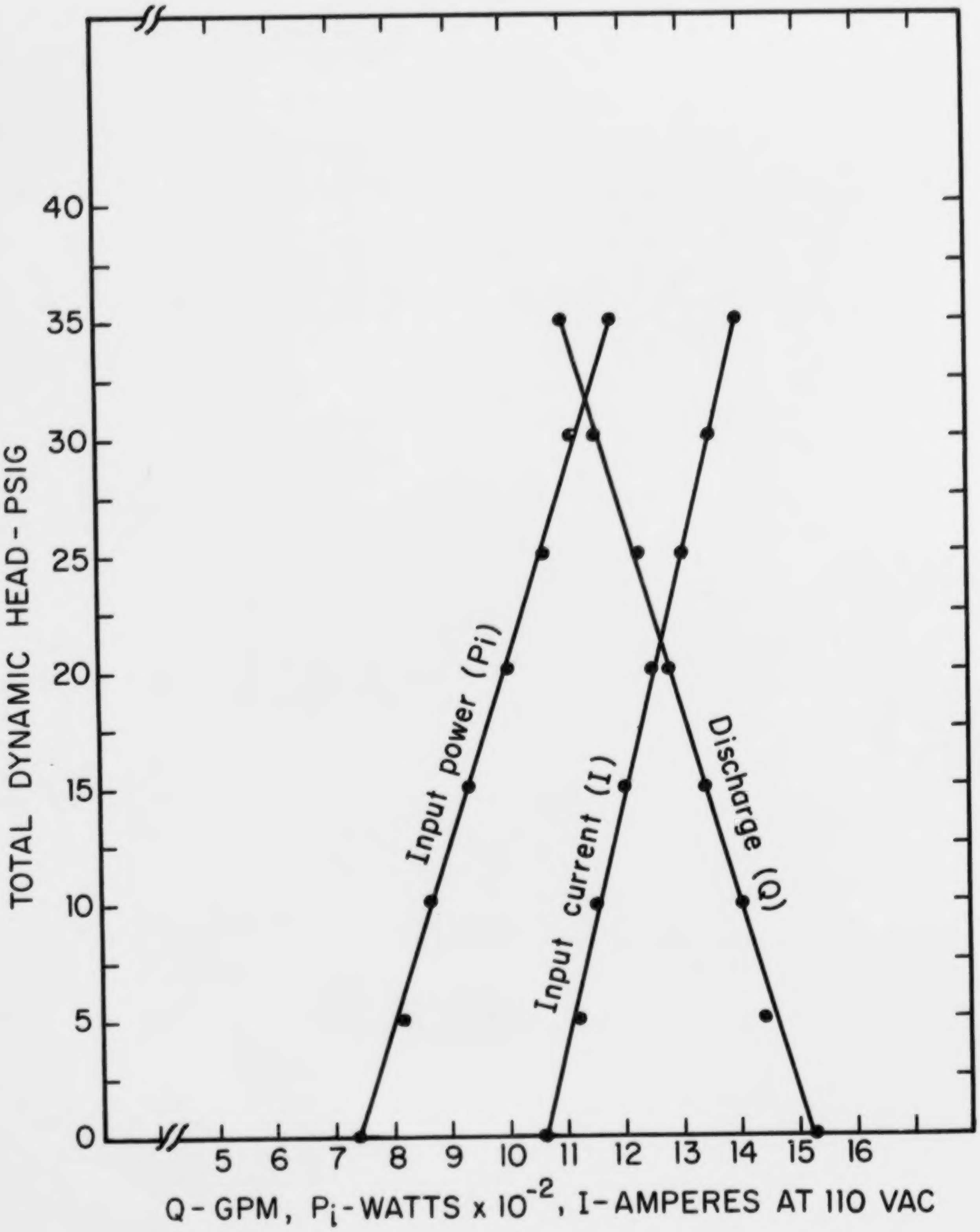


FIGURE 16
CHARACTERISTIC CURVES, PROTOTYPE SGP UNIT
(Reproduced from Fig. 15, Ref. 21)

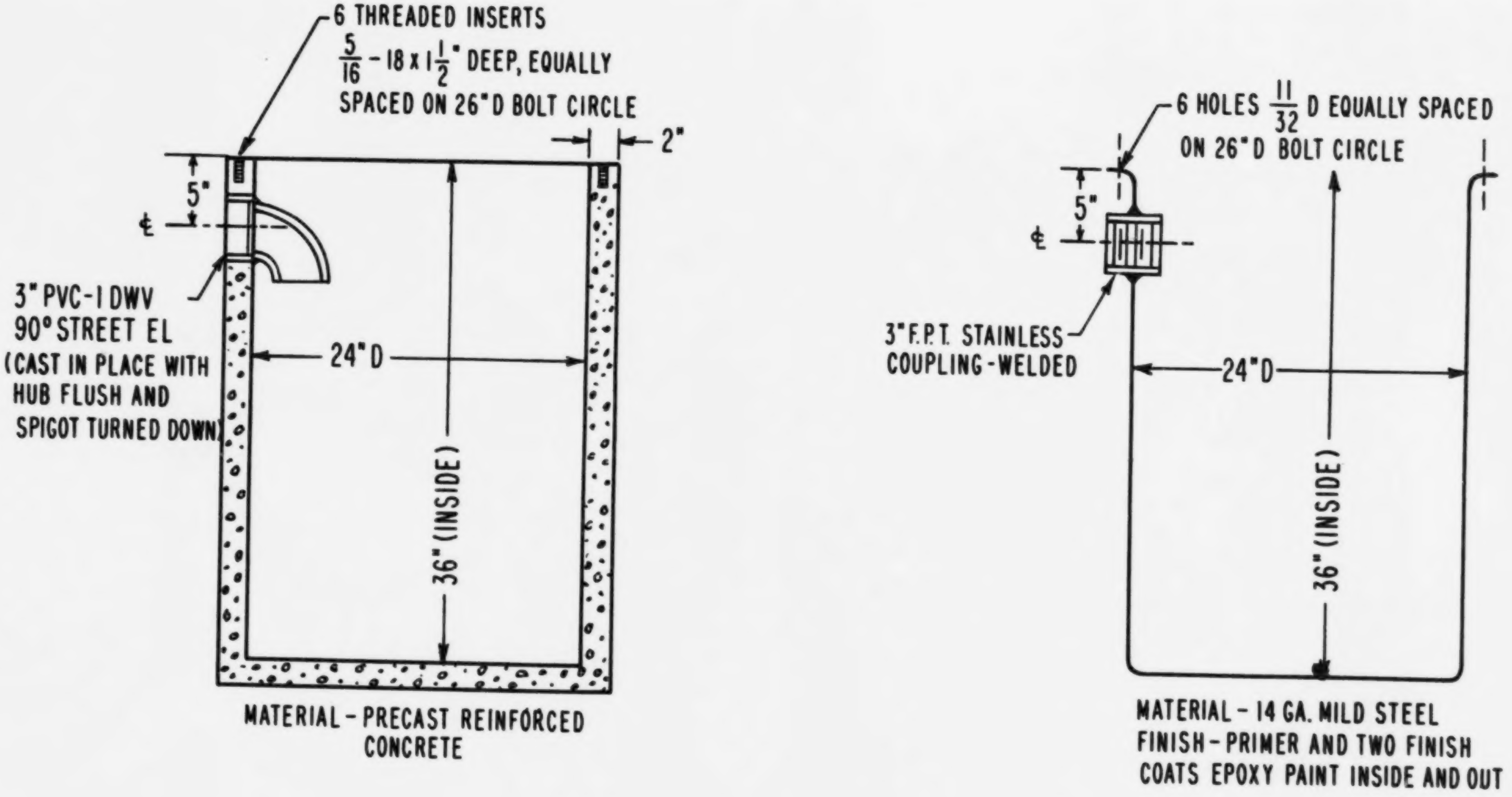

6 THREADED INSERTS
$\frac{5}{16}$ - 18 x $1\frac{1}{2}$" DEEP, EQUALLY SPACED ON 26"D BOLT CIRCLE
2"
5"
℄
3" PVC-I DWV 90° STREET EL (CAST IN PLACE WITH HUB FLUSH AND SPIGOT TURNED DOWN)
24"D
36" (INSIDE)
MATERIAL - PRECAST REINFORCED CONCRETE
6 HOLES $\frac{11}{32}$ D EQUALLY SPACED ON 26"D BOLT CIRCLE
5"
℄
3" F.P.T. STAINLESS COUPLING-WELDED
24"D
36" (INSIDE)
MATERIAL - 14 GA. MILD STEEL
FINISH - PRIMER AND TWO FINISH COATS EPOXY PAINT INSIDE AND OUT

FIGURE 17
TANKS FOR SGP PROTOTYPE
(Reproduced from Fig. 19, Ref. 21)

TABLE 8

SPECIFICATIONS FOR PROTOTYPE STORAGE-GRINDER-PUMP UNIT

(Reproduced from Table 5, Ref. 21)

Motor: 1-HP, 1,725-rpm, capacitor start, thermally protected.

Electrical supply requirement: 230-v, 10-amp, 60-Hz (fused 10-amp); or 115-v, 20-amp, 60-Hz (fused 20-amp).

Electrical Name Plate Rating:
115/230 volts, 13.8/6.9 amp, 60 Hertz, 1 phase, 1,725 rpm, Rise 40° C, Service Continuous, General Electric Mod. 5KC47RG913U.

Inlet Connection: 3" or 4" C.I., copper, or non-metallic DWV may be adapted at tank entrance fitting.

Discharge Connection: 1¼" copper tube (hard drawn) adaptable to 1¼" polyethylene tube outside foundation.

Net weight (not including tank): 150 lb.

Maximum Discharge Pressure: 35 psig.

Discharge: 15 gpm @ 0 psig; 11 gpm @ 35 psig. (Discharge data include losses through check valve which are minimal).

Alternative Equipment

Alternative pumping equipment, including centrifugal, turbine, and positive displacement pumps, and pneumatic ejectors were considered, but it was decided that the need for a steep head-discharge characteristic, freedom from clogging by sewage solids, and good economy of operation could be met best by the progressing-cavity type pump in combination with a separate grinder unit.

Alternatives are discussed in Refs. 3 and 21.

SECTION VI

CONVENTIONAL EQUIPMENT AND CONTROLS FOR STORING, COMMINUTING, AND PUMPING SEWAGE FROM COMMERCIAL BUILDINGS AND OTHER LARGE SOURCES*

Introduction

The ASCE Project requirements for equipment to grind and discharge sewage from sources larger than single and possibly two-family residential buildings (Section V) are based on flow rates developed in Section IV and given in Fig. 9.

The maximum pumping head would be the same at the curb line as for the smaller SGP unit, assumed to be about 30-psig from the hydraulic analysis of the pressure collection system piping in the next section of this report.

Comminuting and Pumping Equipment

To grind and pump discharges above those of single or double installations of the SGP unit (Section V), namely above about 15 or 30 gpm, conventional comminutors and non-clog centrifugal pumps were selected. Comminutor-pump installations have long been in service in sewage works, produced satisfactory records of operation, and provided capacities up to many hundreds of gallons per minute.

The Project staff began a comminutor monitoring program in mid-1966 and pursued it until the end of November 1967 in cooperation with operators of installations. Day-to-day records were kept by the operators and sent monthly to the staff for compilation and analysis.

The installations ranged in size from 4-in. (1,000 gallons per day) to 15-in. (300,000 gpd) and were situated in New York, Florida and Nova Scotia. A summary of the frequency and extent of their maintenance is given in Ref. 3.

Of the 30 installations for which adequate records of past experience were obtained, 16 required no repair or replacements. All but one were less than four years old. Repairs to 7 of the others involved the cutting elements, 3 suffered breakage of gears by stresses incidental to jamming, 1 shaft failed from corrosion and 1 motor burned out. Most of the 30 machines had jammed occasionally or frequently, stopping the machines until the causes of jamming had been removed.

---

* Ref. 3.

Descriptions of comminutor equipment produced by three manufacturers are given also in Ref. 3.

Figure 18 shows the particle size reduction obtained in a single test of a comminutor for raw sewage in comparison with the result obtained in passing sewage through a ½-hp. commercial garbage grinder.

The conclusion reached was that commercially produced comminutors would be adequate for larger buildings in the use of the project scheme. Comminutors were, therefore, included in the hypothetical designs of pressure sewer systems for San Francisco, Milwaukee, and Boston, reviewed and evaluated by consultants, as reported in Section IX.

Combined Grinders and Pumps

The possible use of commercial grinder-pump devices, among them the Gorator (Dorr-Oliver, Inc., Stamford, Conn.), the Stereophagus and Disintegrator pumps (Sigmund Pulsometer Pumps, Ltd., Reading, England) and the Mazorator (Moyno Pump Division, Robbins & Myers, Inc., Springfield, Ohio) was reviewed. Because they require a substantial motor horsepower and have capacities greater than the range considered for household application and for all but the larger commercial applications it was concluded that they might be considered only for larger commercial and industrial uses.

Non-Clog Centrifugal Pumps

Non-clog centrifugal pumps have commonly been used for pumping sewage. They usually have capacities greater than about 10 gpm. Dual installations and pumps of the wet-pit or submerged type in the capacity ranges considered in the ASCE Project appear to be satisfactory.

Because of their general acceptance for sewage pumping, non-clog pumps were included in the comminutor-pump installations for sewage sources larger than those to be handled by single or double SGP unit installations, and they have been included in the designs of hypothetical systems reported in Section IX.

Pneumatic Ejectors

Pneumatic ejectors for sewage are available in capacities of 30 to 1,000 gpm and have been generally accepted for locations where low efficiency can be offset by relative freedom from clogging and complete enclosure of the sewage. Pneumatic ejectors, including air compressors and controls, cost more and require greater space than non-clog pumps of equal capacity. The ability to handle sewage solids of moderate size is of no advantage in their possible application to the ASCE Project,

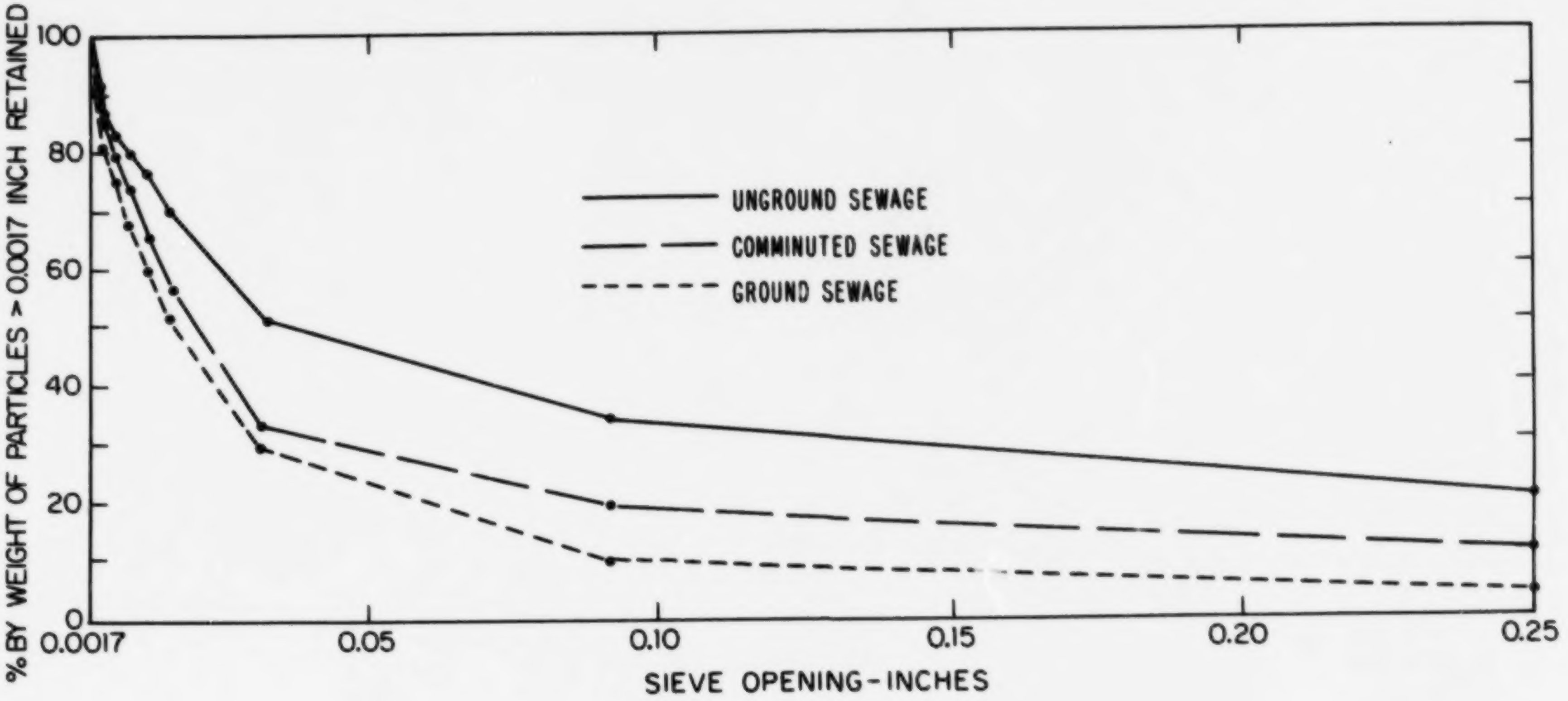


FIGURE 18
EFFECT OF COMMINUTOR AND GARBAGE GRINDER
ON SEWAGE PARTICLE SIZES
(Reproduced from Fig. 3, Ref. 3)

because the solids must be reduced in size for passage through the pressure tubing and valves.

For these reasons, and because of the difficulty of matching the discharge characteristics of pneumatic ejectors with those of the pressure sewer system, they have not been considered for adoption under the ASCE Project scheme.

Cost of Comminutor-Pump Installations

The estimated cost of equipment and installation of a comminutor-pump unit for large buildings in the Milwaukee area was about $2,600: $1,700 for the equipment and $900 for installation. The receiving wet well (Ref. 17) was included, but no allowance was made for contingencies and engineering.

SECTION VII

PRESSURE SEWER SYSTEMS*

Introduction

Design and implementation of the ASCE Project scheme of pressurized sewerage required the following information: present and future maximum, average, and minimum discharge rates of sewage from sources of all sizes; equipment for grinding sewage solids and storing and pumping sewage, together with consideration of head and capacity limitations; available tubing and conduit materials and appropriate methods for their installation and repair; emergency or alternative avenues for routing flows; minimum transport velocities for conveying sewage solids in conduits flowing full; and methods and devices for the control of pressure and rate of flow and the prevention of backflow.

Rates and volumes of sewage generated over short periods of time have been discussed in Section IV. The use of rate of flow curves outlined in Section IV for design of street sewers is detailed and exemplified fully in Refs. 16, 17 and 18. Application of flow data to the selection of pump capacities and storage volumes has been discussed in Section V for small sewage sources and in Section VI for large sewage sources.

Equipment for grinding sewage solids and storing and pumping sewage is described in Section V for small wastewater sources (the household storage-grinder-pump unit) and in Section VI for large sources (comminutor-pump and wet-well installations).

Tubing and Conduit Defined

The term "tubing" as used in this report applies to flexible tubing of relatively small diameter that can be inserted in existing building drains and sewers or buried in a separate trench extending from a building to the street. The term "conduit" is applied to rigid or semi-rigid pipe larger than tubing that can be suspended in existing street sewers of walk-through size or laid in a separate trench.

---

* Refs. 4, 5, 6, 7, 11, 22, 23 and 24.

Materials

The materials considered for pressure tubing and conduit in the ASCE Project scheme are identified respectively in Tables 9 and 10 (from Ref. 23).

The requirements for tubing that is to be pushed or pulled through existing 4-in. and larger inside diameter building service connections were: flexibility and ease of manipulation; resistance to external and internal scoring and abrasion; resistance to structural collapse or flattening; freedom from chemical attack by sewage constituents or trench backfill; freedom from damage by electrolysis; strength equivalent to a bursting pressure at least three times the maximum expected system pressure in order to compensate for the possible corrosive effects of sewage; and commercial availability and economical cost.

The materials considered and recommended for pressure conduit in Table 10 include those commonly used in sewage force mains and meeting the normal requirements of force mains and possessing, in addition, adequate stiffness and beam strength between supports for suspension in existing street sewers.

Insertion of Tubing

The results of field trials of inserting tubing in a building sewer in Washington, D.C., performed by the District Department of Sanitary Engineering in 1967 (Ref. 5) are summarized in Tables 11 and 12. As there shown, 3/4, 1 and 1¼-in. diameter polyethylene tubing was successfully pushed through the building sewer, whereas 3/4 and 1-in. polybutylene and 3/4-in. copper tubing were not. Moreover, polyethylene tubing of all three sizes and 3/4 and 1-in. diameter polybutylene tubing were successfully pulled through the building sewer whereas 3/4-in. copper tubing was not.

Special tools and methods for inserting and connecting tubing to pressure conduits are described in detail in Ref. 23. Included are a leading roller-guide for pushing tubing and special grips for pulling tubing.

Tubing and Conduit Installation

Three alternative methods for installing tubing and conduit are outlined in Fig. 19. In Method A, tubing is inserted in the existing building sewer and connected to a pressure conduit suspended in the existing street sewer. This method can be used only where building sewers are free from obstructions and where street sewers are large enough to install conduit and connect tubing to it. Method A embodies the original pipe-within-a-pipe ASCE Project concept, which is conceded

TABLE 9

TUBING LESS THAN 2 INCHES IN DIAMETER CONSIDERED FOR PRESSURE BUILDING CONNECTIONS

(Ref. 23)

Material and Type	Nominal Size, Inches	Ave. Weight, #/ft.	Type of Fitting	Working Pressure, psi	ID, Minimum, Inches
Polyethylene WST type 3, grade 2	3/4	0.05	flared	160	0.764
3206	1	0.22	"	"	0.983
	1 1/4	0.5	"	"	1.202
Polyethylene WST type 3, grade 3	3/4	0.05	flared	160	0.764
3306	1	0.22	"	"	0.983
	1 1/4	0.5	"	"	1.202
Polybutylene WST type 2, grade 1	3/4	0.05	flared	160	0.796
2110	1	0.1	"	"	1.027
	1 1/4	-	"	"	1.258
Type L Soft Copper Tubing	3/4	0.41	flared	510	0.785
	1	-	"	450	1.015

TABLE 10

PIPE MATERIALS 1½ INCHES THROUGH 16 INCHES IN DIAMETER CONSIDERED FOR PRESSURE CONDUITS (Ref. 23).

Type and Grade of Material	Nominal Size, inches	Ave. Weight, #/ft.*	Working Pressure (psi)	Standard Lengths, Feet	ID, minimum, inches
PVC 1120	1 1/2	0.25	160	20	1.708
(solvent	2	0.39	"	"	2.147
weld	2 1/2	0.57	"	"	2.608
connection)	3	0.85	"	"	3.182
	3 1/2	--	"	"	3.644
	4	1.41	"	"	4.103
	5	--	"	"	5.071
	6	3.10	"	"	6.042
	8	--	"	"	7.866
	10	--	"	"	9.924
	12	--	"	"	11.770
Asbestos	3	5.6	150	13	mandrel
Cement	4	7.0	"	"	sized
Class 150	6	11.7	"	"	-
(compression	8	18.2	"	"	-
gasket	10	30.0	"	"	-
coupling	12	40.8	"	"	-
connection)	14	52.1	"	"	-
	16	64.8	"	"	-
Ductile Iron**	3***	10.5	350	12/18/20	3.68
Pushon Joint	4***	13.4	"	18/20	4.51
(compression	6	21.0	"	18/20	6.59
gasket bell	8	29.7	"	18/20	8.72
and spiggot	10	38.9	200	20	10.40
connection)	12	49.0	"	"	12.48
	14	55.9	"	"	14.58
	16	65.8	"	"	16.66
Cast Iron	2	6.2	150	20	2.0
Class 150	2 1/4	6.8	"	"	2.25
Pushon Joint	3	12.4	"	12/16	3.32
(compression	4	16.5	"	12/16	4.10
gasket bell	6	25.9	"	12/16	6.14
and spiggot	8	37.0	"	12/16	8.23
connection)	10	49.0	"	18/20	10.22
	12	63.4	"	18/20	12.24
	14	78.2	"	18/20	14.28
	16	94.5	"	18	16.32

* Includes fittings

** Assuming wall thickness for 5 foot cover

*** 3 and 4 inch size limited to 1 inch tap

TABLE 11

RESULTS AND OBSERVATIONS OF PUSHING TESTS
(Ref. 5)

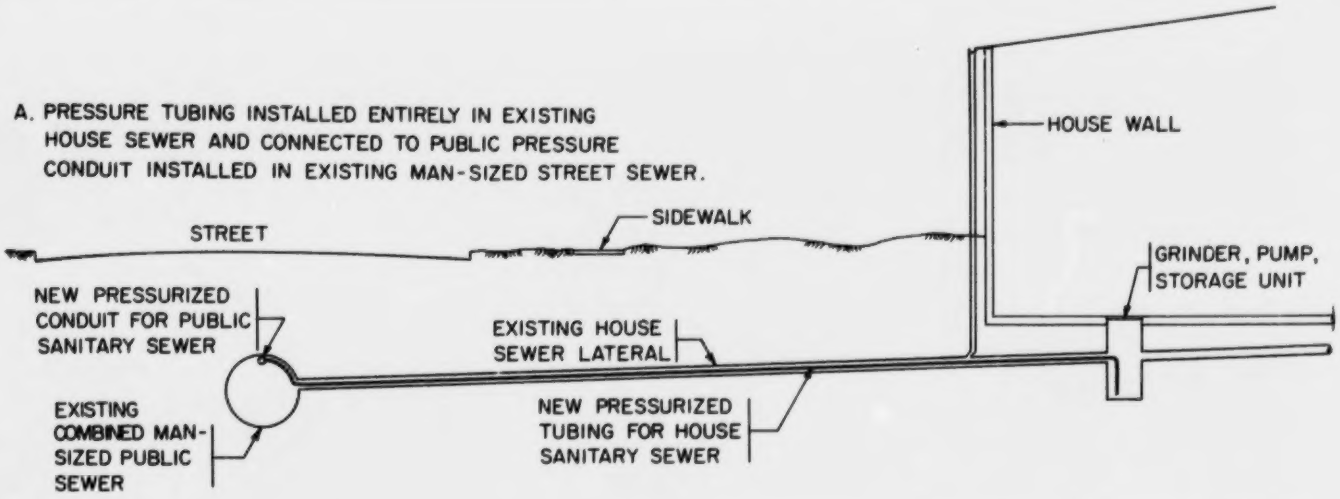
Tubing Material	Nominal Internal Diameter of Tubing (inches)	Calculated Working Pressure of Token Length (psi)	Manufacturer's Rated Working Pressure (psi)	Actual Inside Diameter (inches)	Wall Thickness (inches)	Results	Remarks
Polyethylene	3/4	146	160	.681	.097	Successfully pushed from upper building pit to combined sewer.	One man was able to push tubing through lateral.
Polyethylene	1	165	160	.875	.125	Successfully pushed from upper building pit to combined sewer.	One man was able to push tubing through lateral.
Polyethylene	1 1/4	159	160	1.069	.153	Successfully pushed from upper building pit to combined sewer.	Two men were required to push as hard as possible to get tubing through lateral.
Polybutylene	3/4	154	160	.745	.065	Could not be pushed from upper or lower building pit to combined sewer.	Tubing buckled very easily under a pushing force.
Polybutylene	1	154	160	.957	.084	Could not be pushed from upper or lower building pit to combined sewer.	Tubing buckled very easily under a pushing force.
Type L Soft Copper	3/4	-	510	.785	.045	Could not be pushed from upper or lower building pit to combined sewer.	Tubing was very hard to work with. It would tend to buckle instead of bend. When in lateral it tended to buckle and coil up in lateral.

TABLE 12

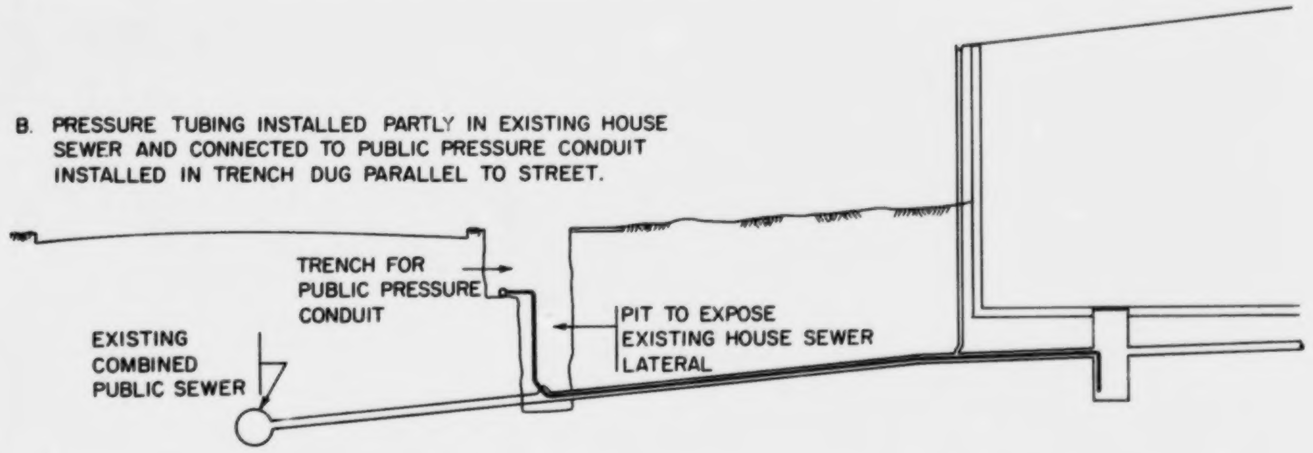
RESULTS AND OBSERVATIONS OF PULLING TESTS
(Ref. 5)

Kind of Tubing	Nominal Internal Diameter of Tubing (inches)	Calculated Working Pressure of Token Length (psi)	Results	Remarks
Polyethylene	3/4	146	Successfully pulled from combined sewer to the upper building pit.	Pulled through by one man. Pulling was more difficult than pushing 3/4" polyethylene.
Polyethylene	1	165	Successfully pulled from combined sewer to the upper building pit.	Pulled through by four men. Pulling was more difficult than pushing 1" polyethylene.
Polyethylene	1 1/4	159	Successfully pulled from combined sewer to the upper building pit.	Pulled through by four men. Pulling was more difficult than pushing 1 1/4" polyethylene.
Polybutylene	3/4	154	Successfully pulled from combined sewer to the upper building pit.	Pulled through by one man. It was easier to pull than the 3/4" polyethylene.
Polybutylene	1	154	Successfully pulled from combined sewer to the upper building pit.	Pulled through by one man. It was easier to pull than the 1" Polyethylene but harder to pull than the 3/4" Polybutylene.
Type L Soft Copper	3/4	-	Could not be pulled from combined sewer to either the upper or lower building pit.	Five men were pulling at the upper building pit. It was apparently stuck between the two 45° bends.

A. PRESSURE TUBING INSTALLED ENTIRELY IN EXISTING HOUSE SEWER AND CONNECTED TO PUBLIC PRESSURE CONDUIT INSTALLED IN EXISTING MAN-SIZED STREET SEWER.


HOUSE WALL
STREET
SIDEWALK
GRINDER, PUMP, STORAGE UNIT
NEW PRESSURIZED CONDUIT FOR PUBLIC SANITARY SEWER
EXISTING HOUSE SEWER LATERAL
EXISTING COMBINED MAN-SIZED PUBLIC SEWER
NEW PRESSURIZED TUBING FOR HOUSE SANITARY SEWER

B. PRESSURE TUBING INSTALLED PARTLY IN EXISTING HOUSE SEWER AND CONNECTED TO PUBLIC PRESSURE CONDUIT INSTALLED IN TRENCH DUG PARALLEL TO STREET.


TRENCH FOR PUBLIC PRESSURE CONDUIT
PIT TO EXPOSE EXISTING HOUSE SEWER LATERAL
EXISTING COMBINED PUBLIC SEWER

C. PRESSURE TUBING INSTALLED ENTIRELY IN A TRENCH DUG FROM HOUSE TO PRESSURE CONDUIT AND CONNECTED TO PUBLIC PRESSURE CONDUIT INSTALLED IN TRENCH DUG PARALLEL TO STREET.

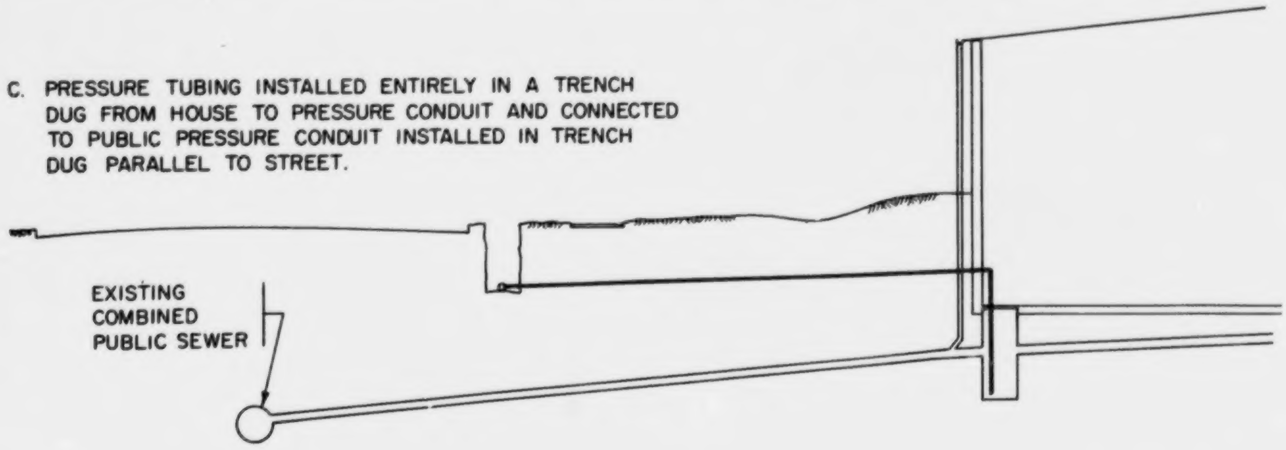


FIGURE 19
ALTERNATIVE METHODS OF INSTALLING AND CONNECTING PRESSURE TUBING AND CONDUIT (ONE SIDE OF STREET, ONLY, SHOWN) (Modified from Fig. 1, Ref. 5)

to be feasible only when street sewers are of adequate size for direct internal access. There appears to be no feasible method for installing pressure conduit in combined sewers smaller in height than about 54-in. without excavating access pits.

In Method C, tubing and conduit are buried in trenches. The existing combined sewer becomes the storm sewer. The trenches are excavated to a depth just below frost penetration. They parallel the ground surface irrespective of its slope. The conduit trench can be placed inside the curb line, or in the street cartway, so as to reduce interference with traffic to a minimum. All four types of tubing in Table 9 are suitable for individual homes.

Method B combines the features of Methods A and C, and might be useful in special circumstances. This method was also demonstrated in the Washington, D.C., field tests (Ref. 5). A building sewer no-hub wye branch was developed especially for this purpose (Ref. 23).

In all three methods, the smaller sizes of conduit in Table 10 can carry the sewage normally discharged through much larger sewers. Construction of the pressure system would closely conform to that of traditional water distribution systems. For these there is abundant precedent.

For Method C in Fig. 19, dual parallel street sewers would be laid in each block, one on either side of the street. It is important to note that this method is applicable to combined sewer separation and for sewering established communities or new developments.

Ranges of Combined Sewer Sizes

A voluntary study of major American cities made for the ASCE Project by the Portland Cement Association (Ref. 4) showed that on an average about 85% of the total length of their combined sewers has an interior clear height of 48-in. or less, and that on an average about 72% of their total length has an interior clear height of 24-in. or less. Supplementary information from the American Public Works Association places the proportion of the larger sizes still lower for cities with under 100,000 inhabitants.

The accepted minimum walk-through size is 54-in. clear interior height. Although the Project staff enjoyed the benefit of much outside advice and assistance, it was unable to devise practicable methods for inserting and securing conduits in sewers smaller than 54-in. and making tubing connections to them without resorting to extensive and expensive street excavations. It must be assumed, therefore, that the pipe-within-a-pipe concept (Method A of Fig. 19) is restricted to about one-seventh the total length of combined sewers in major U.S. cities and to less than this in U.S. communities as a whole.

Suspension of Conduits within Existing Sewers

A hanger system for suspending pressure conduits for sanitary sewage within existing sewers was developed for the ASCE Project by the Research and Engineering Center of the Johns-Manville Products Corporation, Manville, New Jersey, Ref. 24. Single-piece molded polyester hangers were designed for this purpose and epoxy adhesives were used to secure the hangers to the crowns of combined sewers. The basic hanger design was suitable for PVC, ABS, steel, cast iron and asbestos-cement conduits 2 to 12-in. in diameter. The required hanger spacing was based on their ability to support the filled conduits without structural damage to the sewer under a limited conduit deflection.

A trial installation by Johns-Manville was made in an existing 7-ft. diameter concrete intercepting sewer in Evanston, Illinois, in cooperation with The Metropolitan Sanitary District of Greater Chicago in July, 1968. The test section consisted of 100-ft. of 3-in. PVC pipe in 10-ft. pipelengths, supported by 13 polyester pipe hangers. Installation was completed in three nights at times of low sewage flows. The sewer crown surface was cleaned and scored to assure a good bond. The installation was tested structurally. Inspection of the installation after four and one-half months of exposure in the active sewer showed no signs of deterioration of pipe, hanger or epoxy adhesive. Three hangers were later tested to failure in tension at loads of about 2,500 pounds. Failure was by fracture that left the top half of the hanger connected to the sewer crown. In accordance with Ref. 24, the materials and basic method of suspension used are satisfactory for sewers at least about 5-ft. in height provided the sewer itself is structurally capable of sustaining the added distributed load at the crown.

The effect of conduit hangers on the hydraulic capacity of intruded combined sewers is discussed in the next section of this report. For better intruded combined sewer flow capacity and easier conduit installation, a two-part hanger would be preferred. The basic distributed polyester crown seat would be preserved. However, the thick polyester section around the conduit would be replaced by a corrosion-proof thin metal strap and support anchored to the plastic crown seat via an imbedded end plate.

Burial of Tubing and Conduit by Plowing

Field experience with laying conduit by plowing instead of by trenching and burial or jacking is documented in Reference 23. It was concluded that plowing-in 4-in. or smaller pressure conduit (or tubing) is worth investigation, particularly for new subdivisions or for established areas in which driveways are not paved with concrete and there are few buried utilities to be crossed. Plowing is potentially a superior means for burying tubing and/or conduit for Method C of Fig. 19 under the prescribed restrictions. After the National Sanitation

Foundation report (Ref. 23) was completed a more comprehensive survey of plowing methods has been published (Ref. 38).

Other Installation and Maintenance Considerations

Reference 23 also contains information and recommendations on devices for cleaning pressure tubing in the field; tapping procedures and fittings for connecting tubing to conduits, including corporation and curb stops and access manholes; classes of pipe to withstand specific overburden loading conditions; and jacking and tunneling methods for placing tubing and conduit under streets and driveways.

The difficulty of maintenance and repair of street pressure sewers is a direct function of the type of piping layout and the number of valve and clean-out fittings provided. Of considerable concern is the minimization of the number of services that must be interrupted when a section of street sewer is closed off for cleaning, repair, replacement, or other purposes. Six collection system layouts with various advantages and degrees of flexibility for operation and maintenance are discussed immediately below.

Pressurized Sewerage Collection System Layouts

Pressurized sewer systems may be arranged in two basic configurations, dendriform (branched) and reticulate (latticed or looped). In the dendriform arrangement several lateral sewers are connected to a sub-main sewer which, together with other sub-main sewers, is connected to a main conduit serving the pressure-sewer district. The district main discharges into a gravity (open-channel) flow interceptor. Laterals in the reticulate system (single or dual) are connected to sub-main conduits at both ends, and the sub-mains are joined to main conduits that discharge to the interceptor.

For the purpose of providing continuous service to a maximum number of buildings during periods of routine maintenance or in an emergency, and to remove stoppages or replace segments of conduit, systems should be arranged so that portions can be shut down and drained without interruption of service in other portions of the system. For this reason a dendriform arrangement with long single conduits throughout is undesirable and, in the opinion of one consultant, "totally unacceptable." However, in some instances a single conduit might be adequate and less expensive.

The report by the National Sanitation Foundation (Ref. 23) presents six layouts which provide for "routine re-routing without widespread shutdown by virtue of a dual configuration for all or practically all conduits." The first five arrangements were developed by the ASCE Project staff and the sixth was added by the Foundation.

Table 13 outlines the characteristics of the six alternative layouts and comments on their relative merits. Of the six, the nSf Layout (bottom of the table) is the only true reticulate or looped system. Each layout is discussed separately in the remainder of this section, the illustrations used being noted in Table 13.

1. Layout A — The conduit configuration for Layout A is shown in Fig. 20. Flow directions are indicated by arrowheads. Layout A incorporates dual pressure conduits placed in shallow trenches (dug below frost line), one on each side of the street and parallel to it as for Method C, Fig. 19. A portion of the conduit system of Fig. 20 is enlarged in Fig. 21. The dashed lines denote street curbs and the solid lines denote pressure conduits.

Referring to Fig. 21, a portion of the system, say line a between manholes W and X, is isolated by closing the valves on line a in manholes W and X. Flow from line c into manhole X is then diverted across the street to manhole Z where it joins the flow from lines d, e and f and is directed thence through line b to manhole Y. Flow then continues in the direction shown by the arrows. While the flow is being diverted around line a, flows from buildings directly tributary to line a are interrupted. If the shut-down lasts only a short time, say two or three hours during the night, there is little hardship. If the shut-down lasts much longer, however, sewage flows from the buildings must be accommodated in some manner. One possibility is to lay a temporary by-pass conduit on the ground between manholes W and X and to connect the tubing from tributary buildings to the by-pass as in "high-lining" a water main.

It should be noted that for Layout A (Figs. 20 and 21) flow in each line can move in one direction only, except in some of the short sections across streets between dual conduits, such as the sections between manholes X and Z. One of the objectives of this layout and the next four layouts to be discussed is to permit as little looping as possible in order to minimize the residence time of sanitary sewage in the pressure-conduit system.

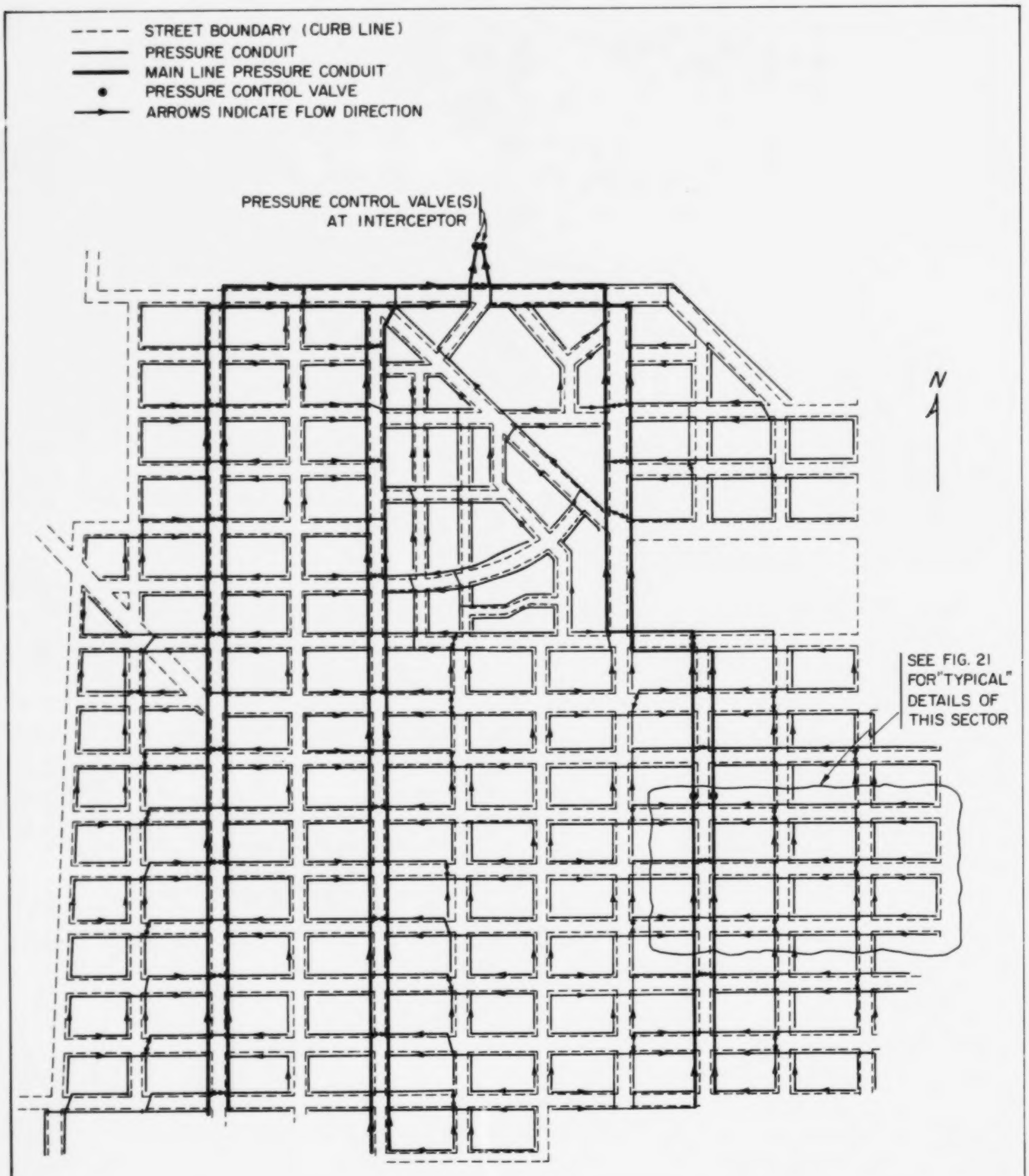
Each intersection has four manholes and various arrangements of clean-out fittings and valves. Manhole diameter depends on the size of the entering and leaving conduits and the arrangement of valves and clean-out fittings. Figure 22 shows the valves and clean-out fittings for manhole W of Fig. 21.

The layout shown in Fig. 21 permits isolating and cleaning the conduits along each block. This is the most elaborate and hence most expensive layout. It is assumed that the greatest reach of pressure sewer that can be cleaned between two access points is one block long (approximately 500 feet). If the length can be increased to two blocks, the valving and clean-out arrangement can be simplified somewhat with a consequent reduction in cost.

TABLE 13

SUMMARY OF CONDUIT LAYOUT CHARACTERISTICS

Ref. 23 Layout Designation	Text Figure Number	Dual Lateral Sewers	Dual Main Sewers	A True Network	Conduits Inserted in Walk-Through Combined Sewers	Auxiliary Conduits Outside Main Sewer	Comments
"A"	20, 21 and 22	Yes	Yes	No	No	No	Most flexible of non-network arrangements.
"B"	23	Yes	Yes	No	Yes, dual without building connections.	Yes	Less flexible than "A".
"C"	24	Yes	Yes	No	Yes, dual with building connections.	No	Less flexible than "A" or "B".
"D"	24	Yes	Dual and Single	No	Yes, single without building connections.	Yes	Less flexible than "A", "B" or "C"; must bypass to storm sewer.
"E"	24	Yes	Dual and Single	No	Yes, single with building connections.	No	Least flexible; must bypass to storm sewer.
"nSf"	25	Yes	Yes	Yes	No	No	Must close 6 valves to clean main; longest sewage residence time.



STREET BOUNDARY (CURB LINE)
PRESSURE CONDUIT
MAIN LINE PRESSURE CONDUIT
PRESSURE CONTROL VALVE
ARROWS INDICATE FLOW DIRECTION
PRESSURE CONTROL VALVE(S) AT INTERCEPTOR
N
SEE FIG. 21 FOR "TYPICAL" DETAILS OF THIS SECTOR

FIGURE 20
LAYOUT A
(Reproduced from Fig. 9, Ref. 23)

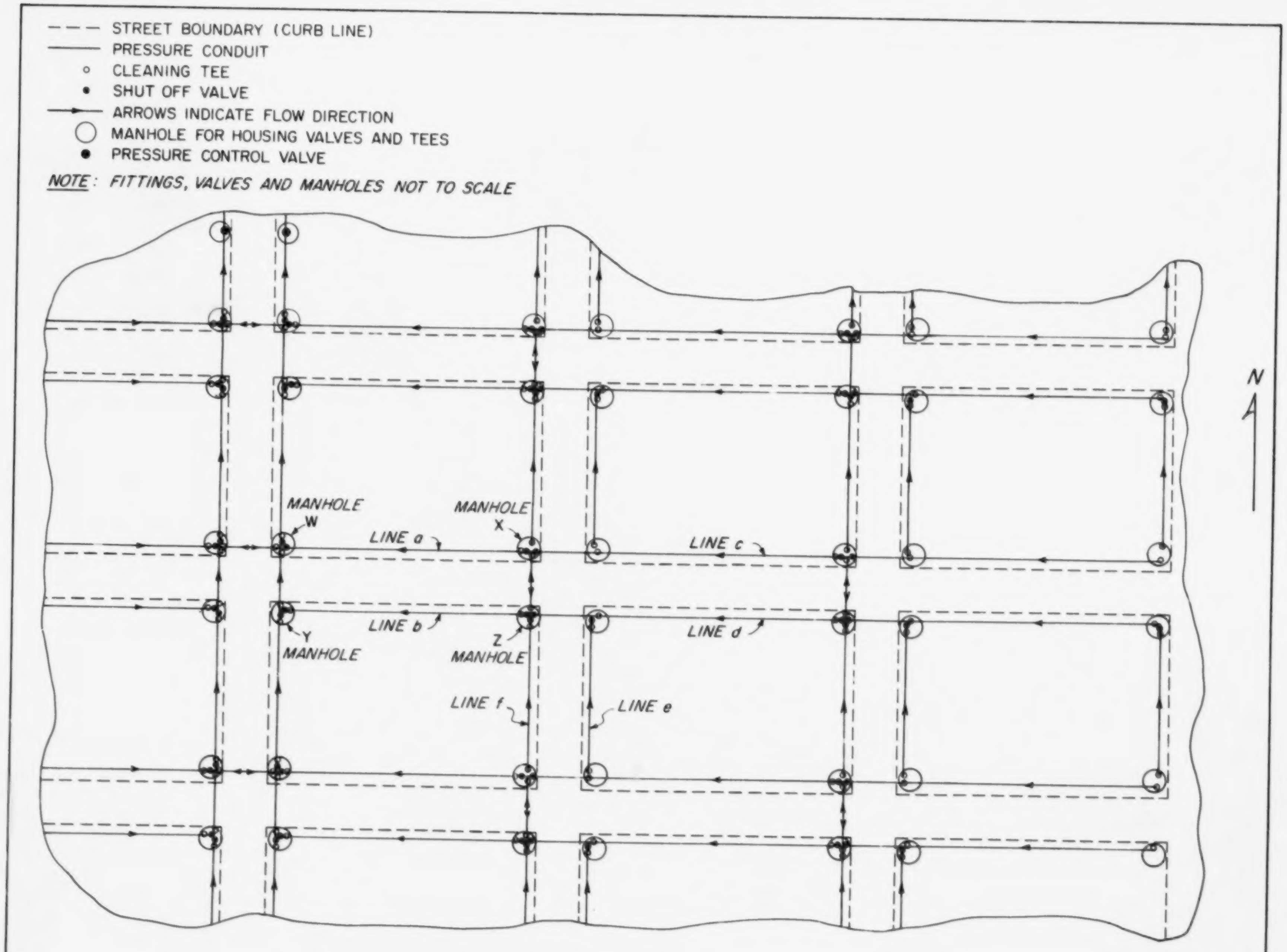
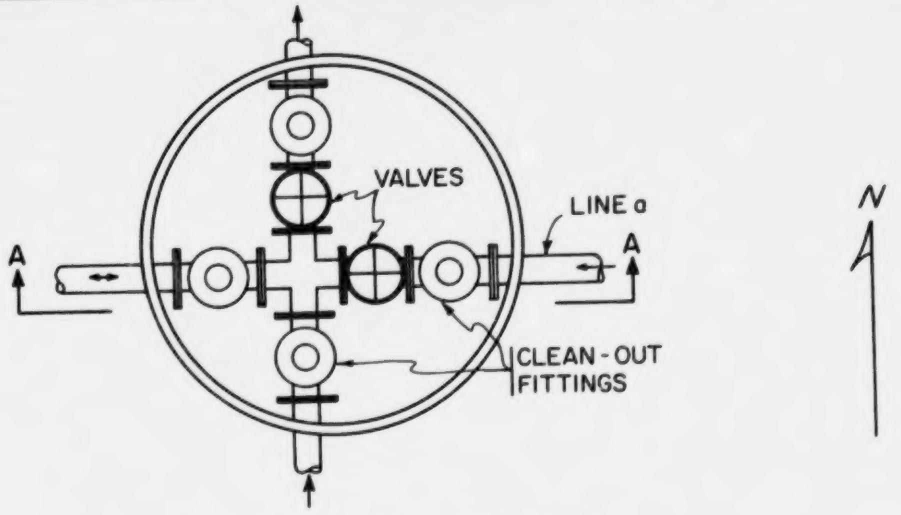

STREET BOUNDARY (CURB LINE)
PRESSURE CONDUIT
CLEANING TEE
SHUT OFF VALVE
ARROWS INDICATE FLOW DIRECTION
MANHOLE FOR HOUSING VALVES AND TEES
PRESSURE CONTROL VALVE
NOTE: FITTINGS, VALVES AND MANHOLES NOT TO SCALE
N
MANHOLE W
MANHOLE X
LINE a
LINE c
LINE b
LINE d
Y MANHOLE
Z MANHOLE
LINE f
LINE e

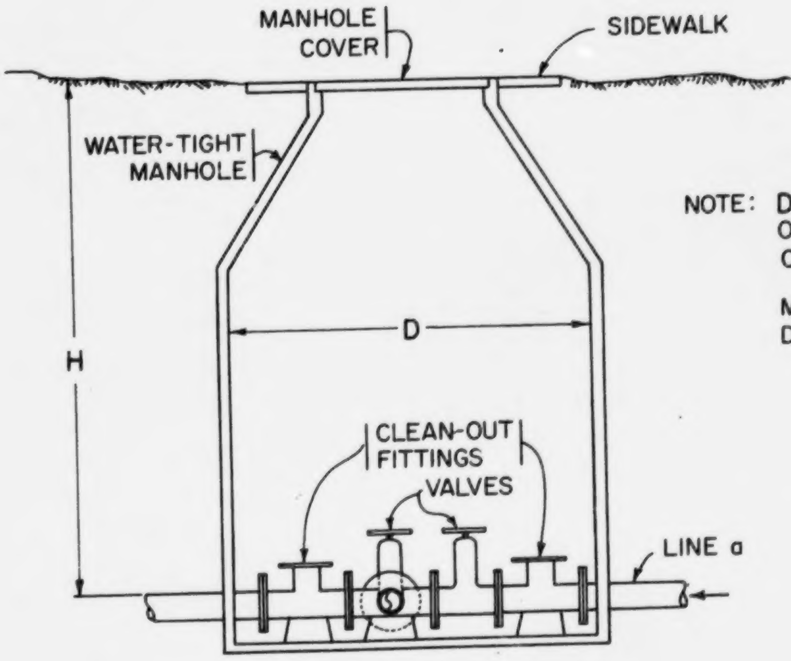
FIGURE 21

LAYOUT A, DETAILS FOR FIG. 20 SECTOR

(Reproduced from Fig. 10, Ref. 23)



PLAN VIEW (INSIDE MANHOLE)



NOTE: D WOULD VARY DEPENDING ON SIZE OF INCOMING AND OUTGOING CONDUITS.

MINIMUM H WOULD BE DEPTH TO FROST LINE.

SECTION A-A

FIGURE 22
LAYOUT A, ARRANGEMENT FOR MANHOLE "W" IN FIGURE 21
(Reproduced from Fig. 11, Ref. 23)

Reference 23 reports on available types of clean-out fittings and established methods of cleaning that might be applied.

2. Layout B — As shown in Fig. 23 the main pressure conduits shown as dual lines in Layout B, as lines g and b, for example, are placed in walk-through combined sewers, but the building tubing is not connected directly to them but to auxiliary dual conduits shown as single lines in shallow trenches on either side of the block. Main conduits along reaches of combined sewers too small to accommodate them, lines c and d, for example, would be placed in shallow trenches as for Layout A.

To isolate a portion of conduit, say line a between manholes R and S in Fig. 23, the same steps are taken as for line a of Layout A in Fig. 21. To isolate a portion of conduit inside a combined sewer, say line b between manholes P and Q, similar steps are taken. The valves in manholes P and Q on line b are closed; the flow entering manhole Q through lines c, d, e, and f then passes through line g to manhole P where it is distributed to the two dual conduits inside the combined sewer.

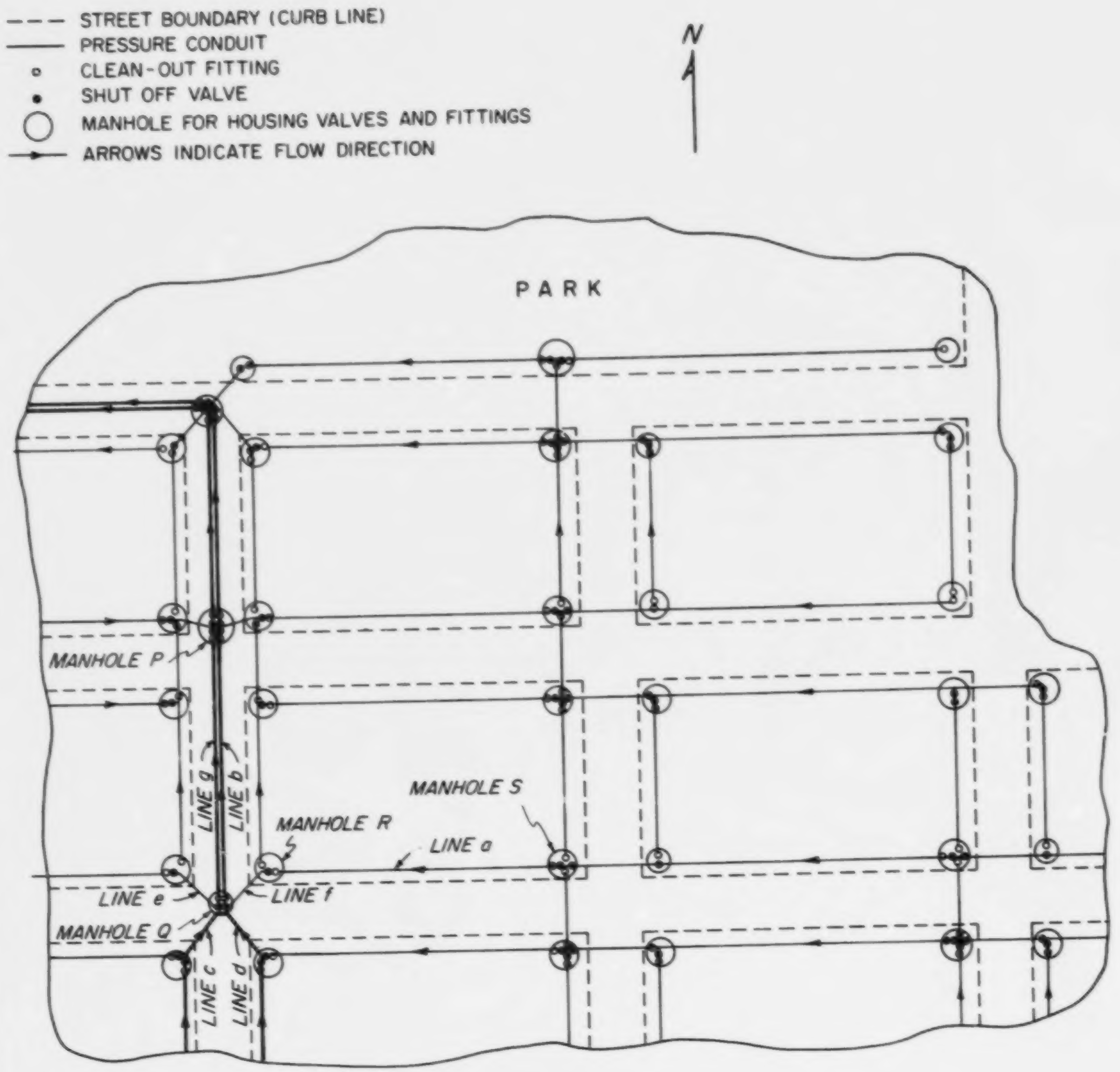
Layout B requires large vaults for valves and clean-outs in manholes P and Q, for example. However, the provision of auxiliary dual laterals makes this arrangement the most flexible and probably most expensive way of inserting main conduits in combined sewers.

3. Layout C — As shown in Fig. 24, Layout C connects household tubing to the dual main conduits inside the combined sewer and eliminates the shallow-trench conduits on the route of the walk-through combined sewers in Layout B. The connections of tubing to conduits are made inside the combined sewer and the tubing is normally fished through the building sewer as in Method A of Figure 19.

From the standpoint of maintenance and operation, this makes for less flexibility than Layout B. Valves and clean-outs in vaults above the combined sewer are the same for Layouts B and C. Only the arrangements in manholes through which auxiliary conduits otherwise pass are changed. Lines are isolated in essentially the same manner in both layouts.

4. Layout D — Layout D in Fig. 24 is the same as Layout B, except that dual pressure conduits inside the combined sewer are replaced by a single conduit.

Isolation of a section of the single pressure conduit for maintenance or repair is accomplished by temporary diversion of sanitary sewage flow to the storm sewer (former combined sewer). This was anticipated by Professor Fair in the original Project scheme. For example, if a blockage occurs in line b of Layout D, Fig. 24, tributary flow is diverted temporarily to the storm sewer by an automatic relief valve located in manhole M. Shut-off valves on line b in manholes L and M are



NOTE: A PORTION OF THIS SYSTEM CONTAINS WALK-THROUGH SIZE COMBINED SEWERS. WHERE THEY EXIST THE MAIN PRESSURE CONDUIT IS INSTALLED INSIDE OF THEM. CONSEQUENTLY, WALK-THROUGH COMBINED SEWERS EXIST WHERE THE MAIN PRESSURE CONDUITS LIE BETWEEN CURB LINES.

BUILDING CONNECTIONS ARE NOT MADE TO THE SEWER-INSIDE-THE-SEWER, BUT INSTEAD TO CONDUITS IN SHALLOW TRENCHES ON EACH SIDE OF THE STREET. THESE CONDUITS IN TURN CONNECT TO THE SEWER-INSIDE-THE-SEWER, AT EACH INTERSECTION.

THE FITTINGS, VALVES AND MANHOLES ARE NOT TO SCALE.

FIGURE 23

EXAMPLE OF LAYOUT B

(Reproduced from Fig. 13, Ref. 23)

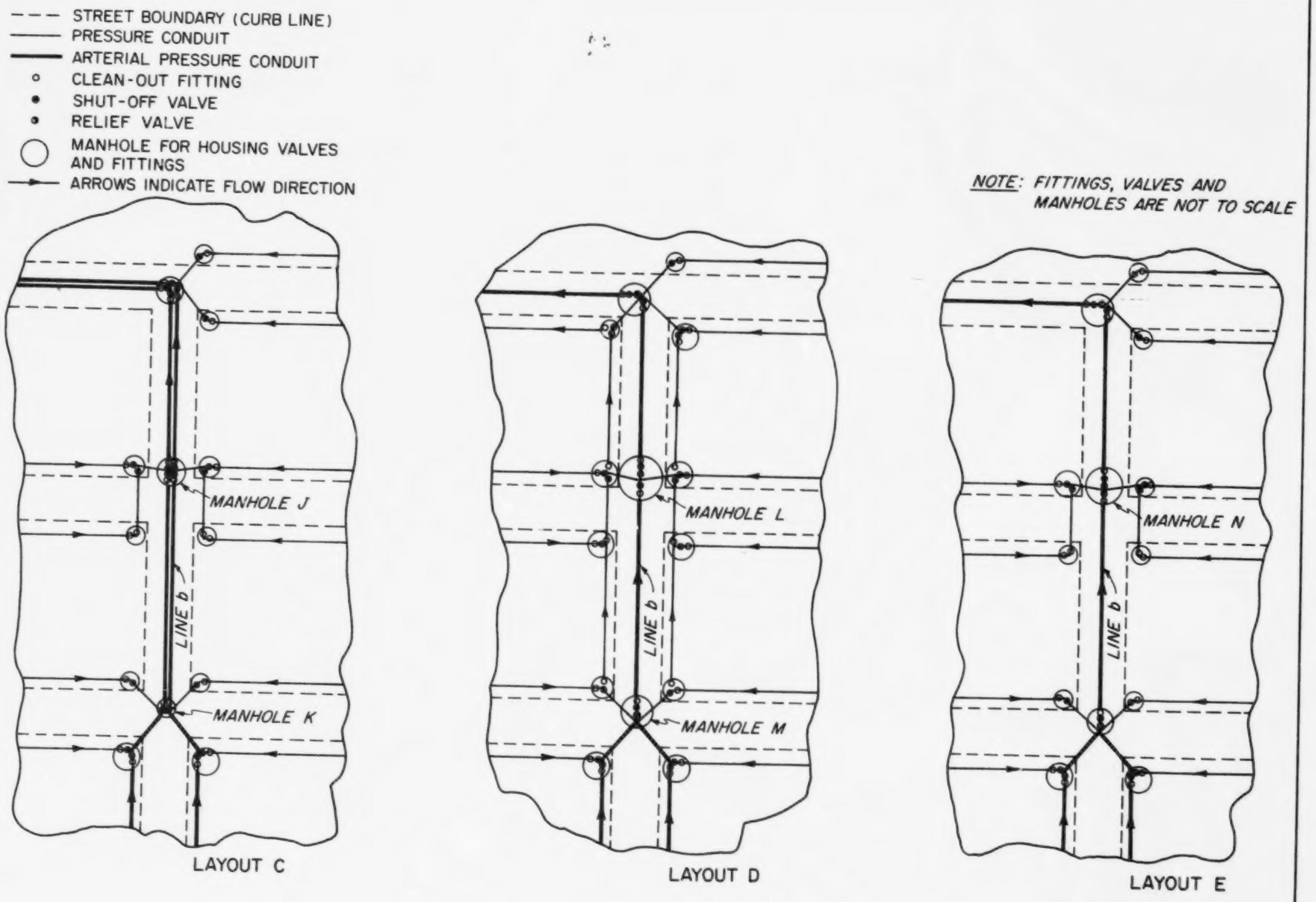

STREET BOUNDARY (CURB LINE)
PRESSURE CONDUIT
ARTERIAL PRESSURE CONDUIT
CLEAN-OUT FITTING
SHUT-OFF VALVE
RELIEF VALVE
MANHOLE FOR HOUSING VALVES AND FITTINGS
ARROWS INDICATE FLOW DIRECTION
NOTE: FITTINGS, VALVES AND MANHOLES ARE NOT TO SCALE
MANHOLE J
LINE b
MANHOLE K
LAYOUT C
MANHOLE L
LINE b
MANHOLE M
LAYOUT D
MANHOLE N
LINE b
LAYOUT E

FIGURE 24
LAYOUTS C, D AND E
(Reproduced from Fig. 15, Ref. 23)

closed to isolate line b for cleaning or repair. While line b is out of service the sewage flows by gravity from the point of diversion through the storm sewer to the interceptor.

5. Layout E — Layout E in Fig. 24 creates the least flexible scheme by combining the less flexible features of Layouts C and D, using Method A in Fig. 19.

Line b in Layout E is isolated in the same way as line b in Layout D, except that flows from buildings tributary to line b must either be interrupted or disconnected, flow being diverted into the storm sewer or elsewhere during maintenance or repair.

6. National Sanitation Foundation Layout — In the pressure-sewer layout shown in Fig. 25, a valve and a tee are installed for cleaning purposes at intervals of about 600 feet or at the ends of each block. After a blockage has been located, up to six valves must be closed before a section of main sewer can be cleaned. The valves are situated at opposite ends of a two-block main sewer and at the end of each tributary lateral sewer. To clean a lateral sewer only two valves must be turned. The flow pattern in this layout is such that when a line is shut down a maximum number of alternative routes are opened up to tributary flows. This advantage is offset in part by the disadvantage of encouraging a longer sewage residence time in the system than in Layouts A through E. Moreover, it is difficult to adapt the nSf Layout to irregularly-shaped pressure districts of varying block size.

Conduit Sizing

Pressurized sanitary sewers must be sized to ensure the creation of minimum scouring velocities often enough to prevent stoppages. Wastewater flows are bound to be low in the course of each day, and solids are bound to be deposited at such times. The longer the time of non-deposition provided for, the smaller must the conduit be. The smaller the conduit is, the steeper does the hydraulic gradient become for all flows. Peak rates of flow produce maximum hydraulic gradients, and these in turn determine pressure requirements within the system, for all pumping and pressure control. Thus, a compromise must be reached between the degree of solids transport effected and system pressure levels deemed tolerable from the standpoint of other hydraulic criteria or as imposed by economic considerations.

Because design criteria for minimum transport velocities of sewage solids in pressure pipes were not available, special research was conducted at the Central Engineering Laboratories of the FMC Corporation in Santa Clara, California (Ref. 22). Raw sewage, with and without reduction of the size of its particulates by comminution was passed through smooth 2-in., 3-in., 4-in., 6-in., and 8-in. I.D. pipe. (A few tests were also run with an 8-in. spiral corrugated pipe and exploratory open-channel tests were made with the smooth 8-in. pipe).

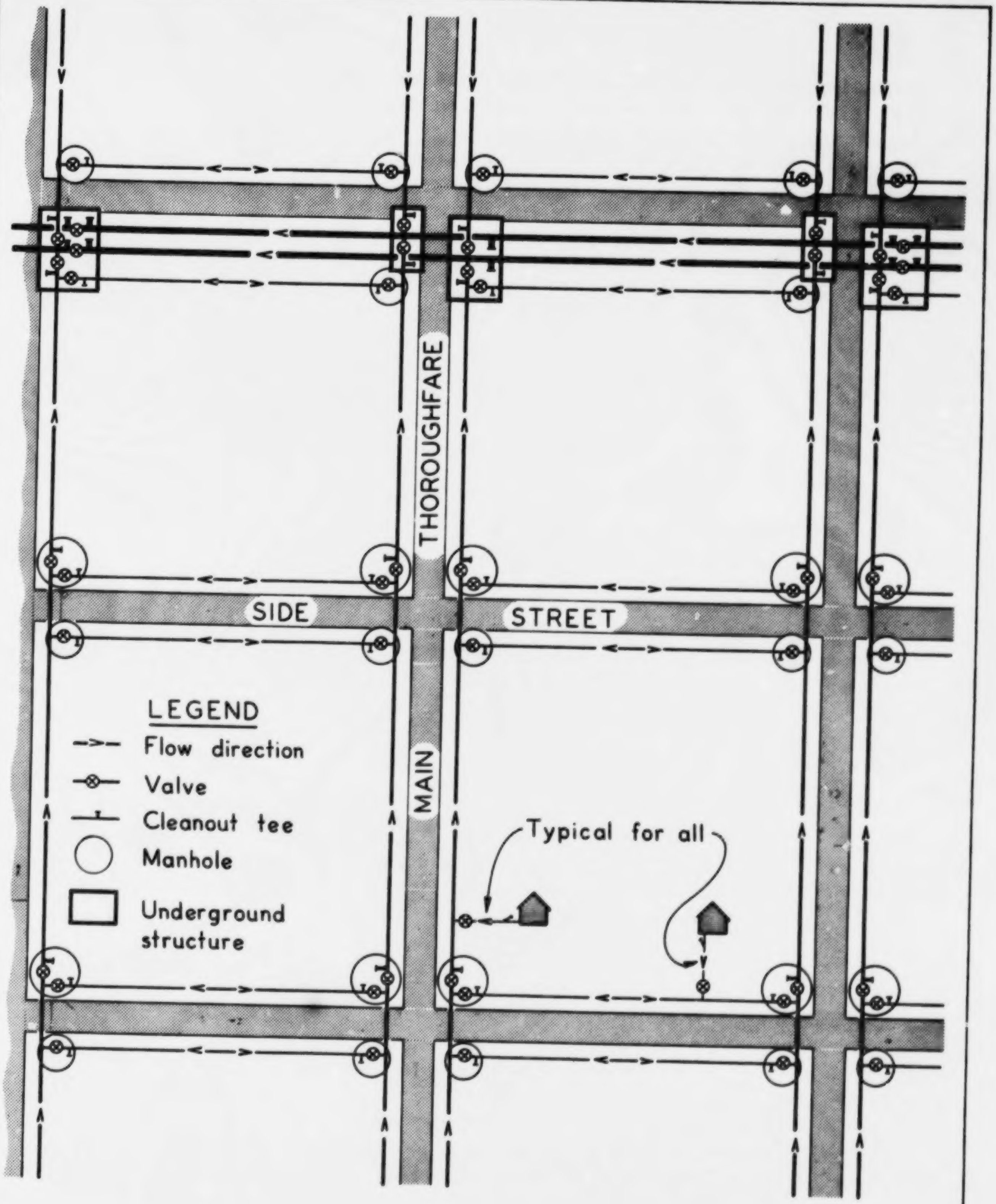


FIGURE 25
NATIONAL SANITATION FOUNDATION PRESSURE SEWER LAYOUT
(Reproduced from Fig. 17, Ref. 23)

Extensive observation showed that sand was predominantly the sewage constituent that was scoured last and deposited first. In all tests the sewage was "salted" with ground egg shells, but these were always moved at lower mean velocities of flow than the sand, which was present only in low concentrations, viz., 8 to 78 ppm. There was no discernable difference between minimum transport velocities for flows with and without particle-size reduction, because the weight of sand was not affected. The minimum scouring velocities tended to be greater than the maximum depositing velocities, but the difference was small. The minimum mean transport velocity in feet per second was found to approximate $\sqrt{D}/2$, where D is the interior pipe diameter in inches, e.g., the minimum velocity for a 4-in. pipe is approximately 1.0 fps. More precise values (Ref. 7) require accounting for sand concentration. Data on minimum transport velocity of sanitary sewage were combined with other data on sand transport. The unified results are given in detail in Reference 7.

For the design of hypothetical pressure-sewer systems in the Milwaukee and San Francisco study areas (Section IX) the lowest peak hour rate of any day for the given number of tributary residences was combined with the minimum transport criteria to size the street pressure-conduits. The highest peak hour rate of any day for the given number of tributary residences was then used to estimate the maximum hydraulic gradients for the size of conduit selected. As explained in Section IV, highest peak-hour flow rates were estimated by applying to metered mean-annual winter-quarter water-demands projected into the future the ratios indicated by the curves in Fig. 7 for the Milwaukee study area and Fig. 8 for the San Francisco study area. With minor modification, essentially the same procedure was followed in connection with the Boston study area using Fig. 9. In all three cases the lowest peak-hour was similarly determined, but beginning-of-design-period demands were used instead. These are normally the lowest and hence the most critical flow rates in terms of solids transport.

System Hydraulics and Controls

The operating pressure ranges of pressurized systems are determined by the hydraulics of a given reach and its domination by hydraulic regime controls at either end of the reach. In the ASCE Project scheme, sewage from a pressure-sewerage area ultimately discharges into an intercepting sewer. It would be difficult to develop a pressurized interceptor and sewer system in which the sole control was a valve at the downstream end of the interceptor. Pressure ranges in the interceptor and throughout the connected sewerage districts would then be dominated by a single control point. More importantly, a large pressure system would generally be constructed in stages, and each stage would require the use of at least temporary controls befitting that stage. Consequently, each pressure service district should be hydraulically independent of the pressure magnitudes and variations in the interceptor to which it is tributary.

This calls for a regulating valve wherever a trunk pressure sewer joins an interceptor.

As flow in a pressure district approaches zero, the hydraulic gradients for all branches approach the horizontal. To maintain a positive conduit pressure during extremely low flows, therefore, the associated flat hydraulic gradient must be artificially raised and held above the highest ground elevation in the district, as illustrated schematically by the ground profile, conduit profile and minimum-flow hydraulic grade-line in Fig. 26.

Assuming that at least some of the buildings are served by household storage-grinder-pump units, the upper pressure range is limited by the maximum total dynamic head of 35-psi for which the units are designed (Section V), or by a maximum curb pressure of 30-psi if 5-psi is allowed for friction and elevation pressure attrition in transmitting the sewage from the household unit to the street sewer. The limiting level for hydraulic grade lines equal to ground elevation plus 30-psi is also shown in Fig. 26.

A constant-pressure valve and a flow-responsive valve are the two basic types of pressure control valves. If case "A" in Fig. 26 depicts the hydraulic grade line for maximum flow, a control valve set to hold a constant pressure head at about 75-ft. will restrict all hydraulic gradients to the range between that maximum and the minimum hydraulic grade line. If the hydraulic grade line for maximum flow was depicted by case "B" in Fig. 26, it becomes necessary to use a flow-responsive control valve that will provide pressure heads of about 75-ft. at minimum flow, of about 40-ft. at maximum flow, and meet all intermediate flows without letting the hydraulic grade line pass above the ground line level plus 30-psi or below the ground line level itself.

Where the topography is steep, a service district may have to be subdivided into pressure zones in which the hydraulic gradients are regulated by separate zonal control valves as shown in Fig. 27. Where the topography is flat or adverse, in-line booster pumping stations will usually be required as well as interceptor and perhaps zonal control valves as shown in Fig. 28.

Major system-pressure transients can originate at the system control valves but such pressure rises can be constrained by proper valve-stroking design. For a street sewer system maintained under pressure at all times, the extent of over-pressure and under-pressure can therefore be regulated by proper valve actuation. Even though large air pockets would not usually be created in a continuously pressurized system, it will still be necessary to provide air release-air inlet valves at the summits of the system.

Because the total dynamic head of centrifugal pumps declines with flow through-put and the opposite characteristic is desired for the type

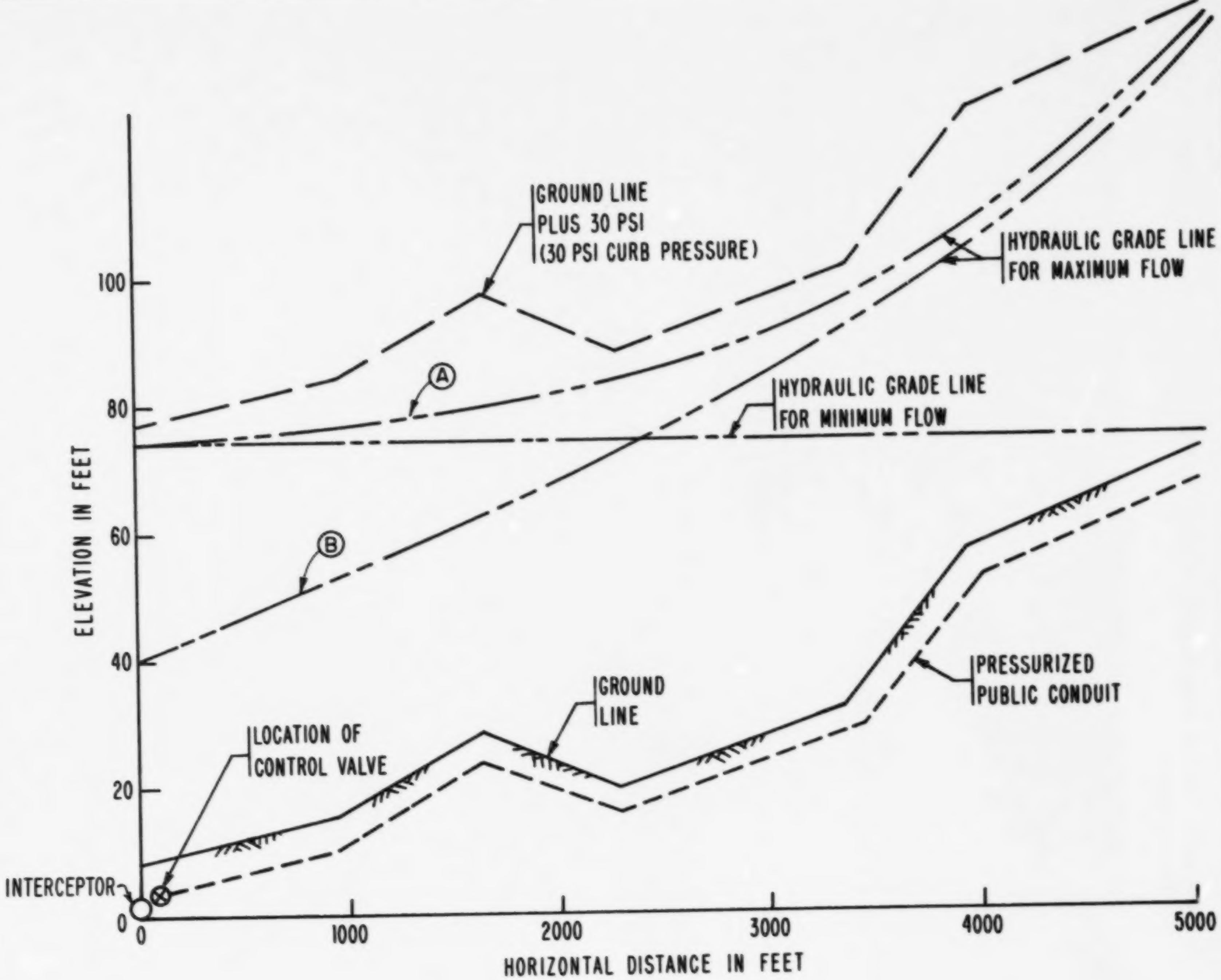


FIGURE 26

EXAMPLE OF MINIMUM AND MAXIMUM HYDRAULIC GRADE LINES

(Adapted from Ref.6)

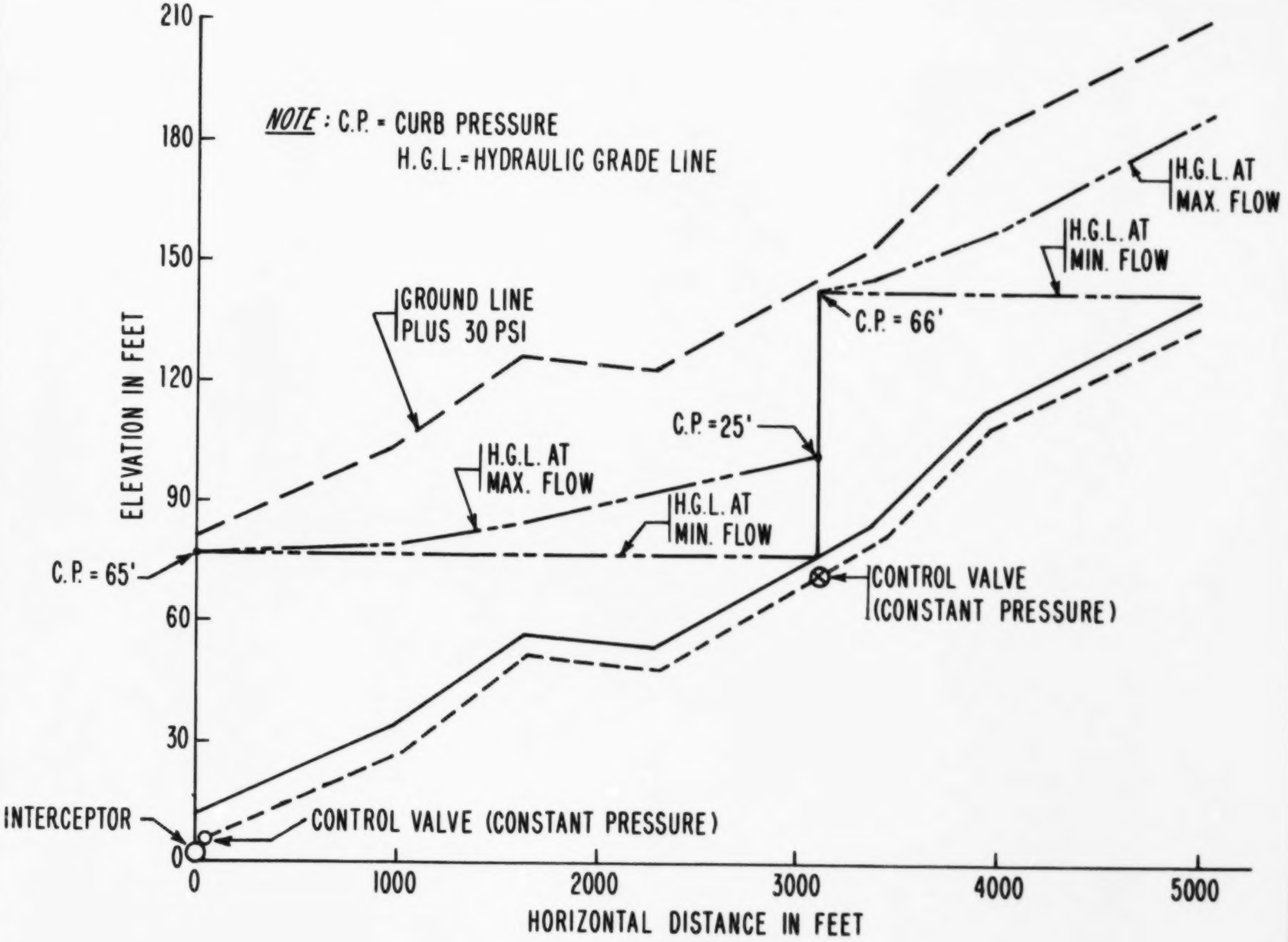


FIGURE 27
EXAMPLE OF PRESSURE ZONE CONTROL
(Reproduced from Fig. 8, Ref. 6)

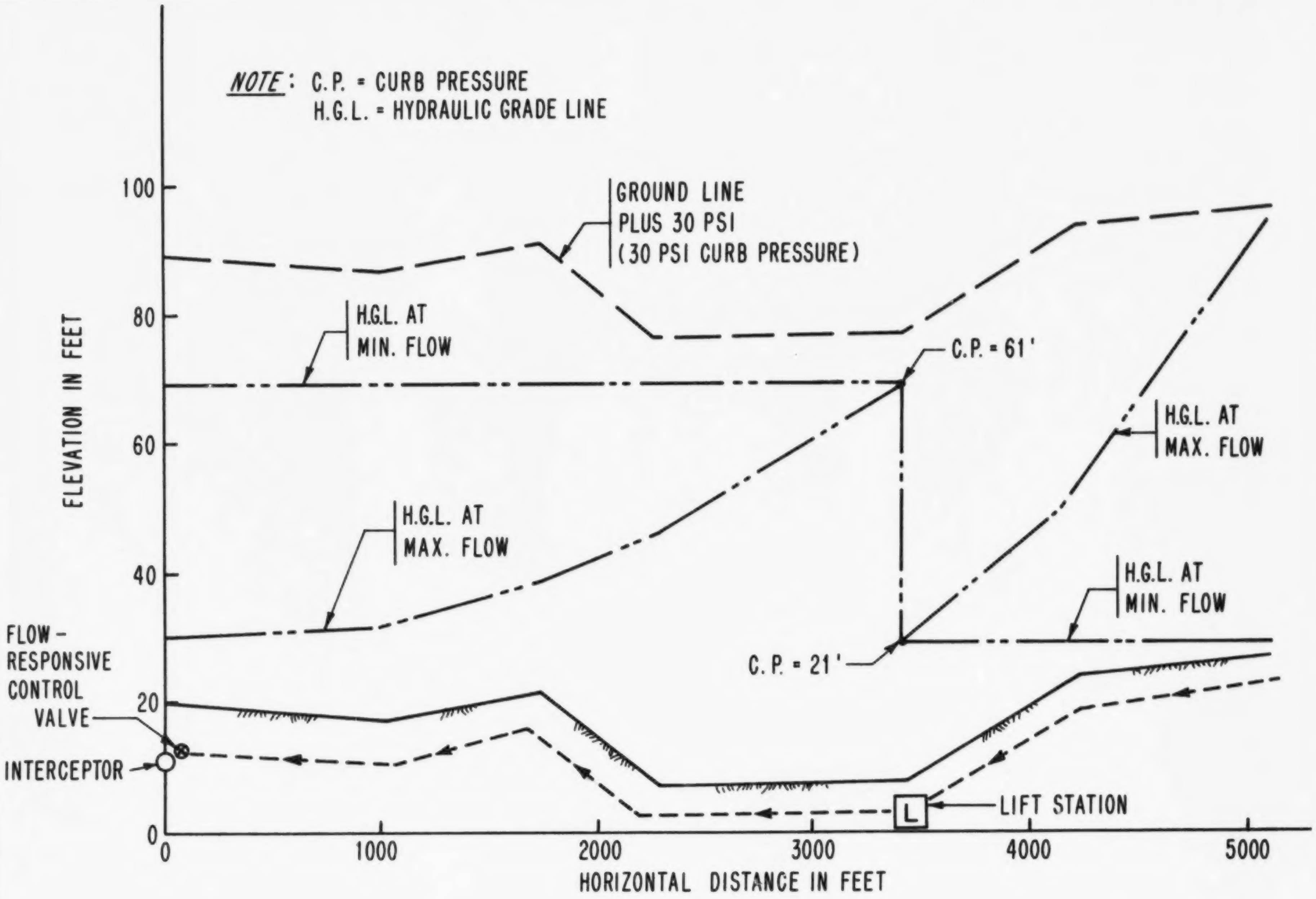


FIGURE 28
EXAMPLE OF IN-LINE PUMPING
(Reproduced from Fig.7, Ref.6)

of system at issue, pumps must be selected with great care for large sewage sources in pressurized sewer systems in order to insure meeting the full range of required operation.

Reference 6 contains a comprehensive summary of hydraulic considerations in pressure sewerage including those for source and in-line pumping as well as district and zone pressure control. Devices and techniques for controlling pressurized sewer systems are covered in Reference 11. Both references deal with readily available equipment and techniques already developed for water works service. Their full applicability to the handling of wastewater that has been passed through a grinder must be determined in future field demonstrations (Section XIV). Reference 11 discusses devices for back-flow prevention in comminutor-pump installations in large buildings. The check valve developed for the prevention of back-flow in household storage-grinder-pump units is described in Reference 21.

SECTION VIII

INSTALLATION OF THE PROJECT SCHEME IN EXISTING SEWERS*

Introduction

Important in the evaluation of the ASCE scheme of inserting small-diameter tubing into existing building drains and sewers and introducing suspended conduits into existing street sewers is (1) the associated reduction in the capacity of the building drains and sewers that convey roof and yard drainage to street sewers and of the sewers to convey storm water flows to receiving waters, (2) the increased danger of stoppages by debris caught between the tubing and the pipe walls, and (3) the increased difficulty of cleaning and repairing both building and street sewers.

Relative Cost and Reliability of Pressure System

Studies made by consultants for ASCE on hypothetical pressure systems for San Francisco, Milwaukee and Boston (Section IX) agree (1) that the costs of such systems will be greater than those of conventional combined-sewer separation; (2) that the service reliability of the pressure system will be less than that of separated gravity systems; and (3) that pressurized systems will be subject to more outages and stoppages than the gravity systems.

Effect of Inserted Pipes on Hydraulic Capacity of Sewers

Under a subcontract with the ASCE Project, the Department of Theoretical and Applied Mechanics of the University of Illinois prepared two reports on the "Effect of Inserted Pipe on Flow Capacity of Sewers," References 25 and 26. Investigated was the hydraulic behavior of conduit sections within which the insertion of circular sections leaves ring-shaped flow areas. Much pertinent information was available in published studies on heat transfer tubing in boilers and other heat exchangers and in theoretical fluid dynamics. Pertinent references are included in the University of Illinois reports.

In the Illinois experiments, turbulent flow was studied in a 100-ft. long, 6-in. diameter, pressure line in which 3/4-in. and 1 1/2-in. pipes could be inserted in critical positions. Maximum velocities of flow were over 20-ft. per second and minimum velocities were about 2-ft. per second. The pipe walls were hydraulically "rough."

---

* Refs. 24, 25 and 26.

The ratio of the inside diameter, D_o, of the outside pipe to the outside diameter, D_i, of the inside or inserted pipe, designated by the symbol $\underline{a} = D_o/D_i$, and the eccentricity of the insertion, given the symbol $\epsilon = \Delta C/\frac{1}{2}(D_o - D_i)$, where ΔC is the offset of the center of the inserted pipe from the center of the outside pipe, were varied. Observed flow resistance coefficients or friction factors were related to the hydraulic radius interpreted as the ratio of the area of flow to the total wetted perimeter.

Experimental results for concentric annulus friction-factor ratios associated with different pipe-diameter ratios are plotted in Fig. 29, together with values obtained by others in earlier studies. The University of Illinois results are shown as double circles. Although there is considerable scatter in the results obtained by different experimenters, it appears that the following conclusions can be drawn: (1) at a diameter ratio near unity ($D_o/D_i = 1$), the friction factor for concentric annular conduits is about 10% less than that of an unobstructed pipe; (2) the friction factor ratio increases thence rapidly with increasing diameter ratios to a maximum value about 10% above the reference value $f_a/f_p = 1$ up to a diameter ratio of about two; and (3) after that the friction factor ratio drops off slowly towards unity as the diameter ratio increases further and lies only slightly above that for an unobstructed pipe at a diameter ratio of six.

Fig. 30 identifies as curve A from Fig. 29 the ratios of friction factors for the concentric annulus, and as curves B, C and D the ratios of friction factors for annular eccentricities ϵ equalling 0.667, 0.90 and 1.00, that obtain at diameter ratios $\underline{a}$ ranging from 1 to 8. The effect of eccentricity is seen to be considerable when the inserted pipe is nearly of the same diameter as the outer pipe ($\underline{a} = 1.2$) and is placed against the inner wall of the larger pipe at maximum eccentricity. The friction factor is then reduced to 64% of its concentric value. This reduction decreases as the relative size of the inserted pipe becomes smaller and reaches 82% when the diameter of the inserted pipe is one fifth that of the outer pipe, i.e., when $\underline{a} = 5.0$. The mode of friction reduction at eccentricities between zero and one is suggested in Fig. 30, but it is based on limited data.

Flow capacity is a function of friction factor and cross-sectional area of flow for a given hydraulic gradient. For a diameter ratio, $\underline{a}$, close to 6, with the inserted pipe suspended by slender rods spread about 14 D_o apart and held in place by thin wires in tension, the flow capacity is reduced by 12.7 per cent at zero eccentricity (concentric pipes). At full eccentricity, i.e., when the inner pipe rests against the outer pipe, on the other hand, the reduction is only 4.5%, probably because the inserted pipe is within a region of lower intruded pipe velocities.

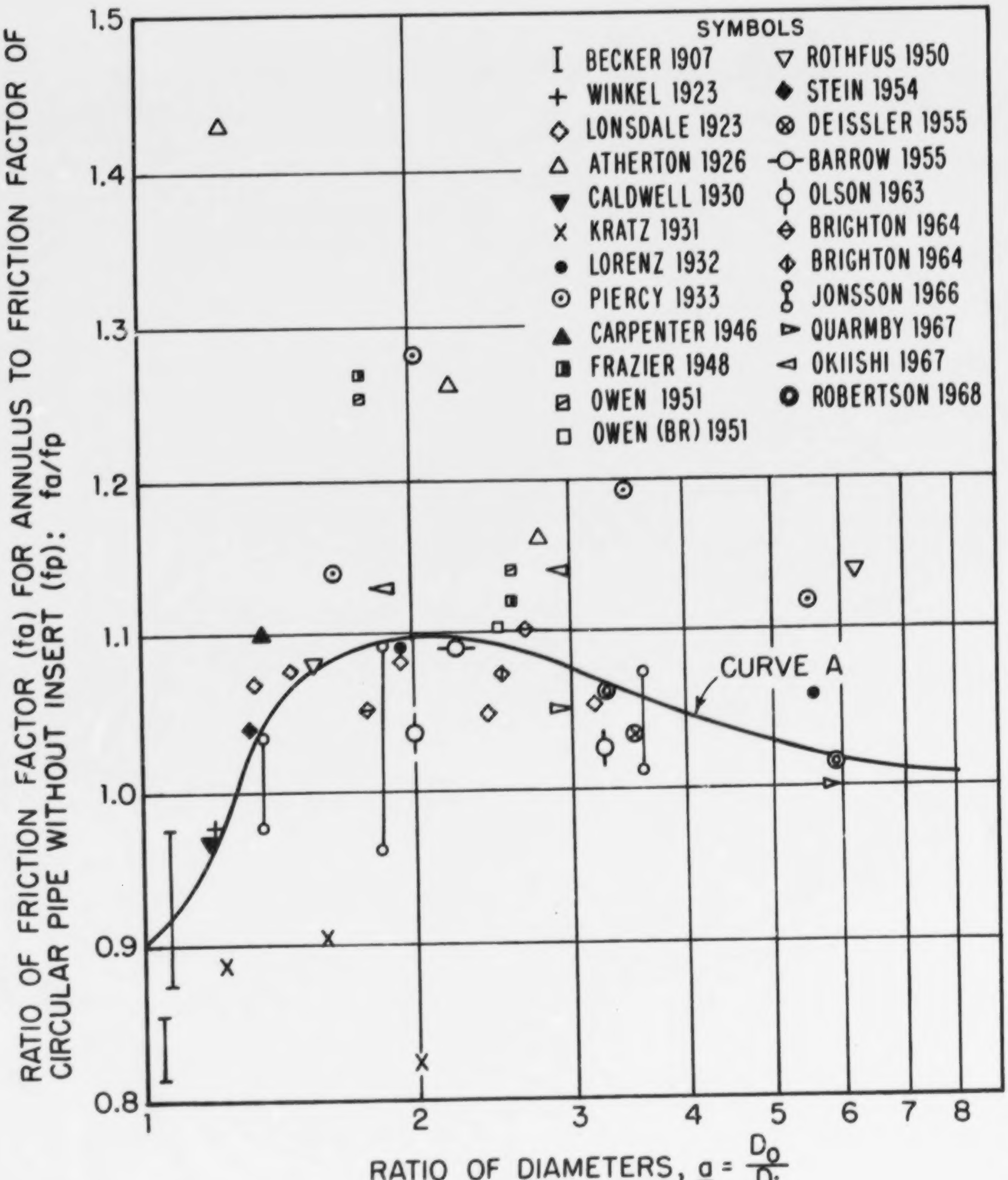


FIGURE 29

TURBULENT-FLOW FRICTION FACTOR FOR CONCENTRIC ANNULUS AS A FUNCTION OF DIAMETER RATIO

(Modified from Fig. 1, Ref. 25)

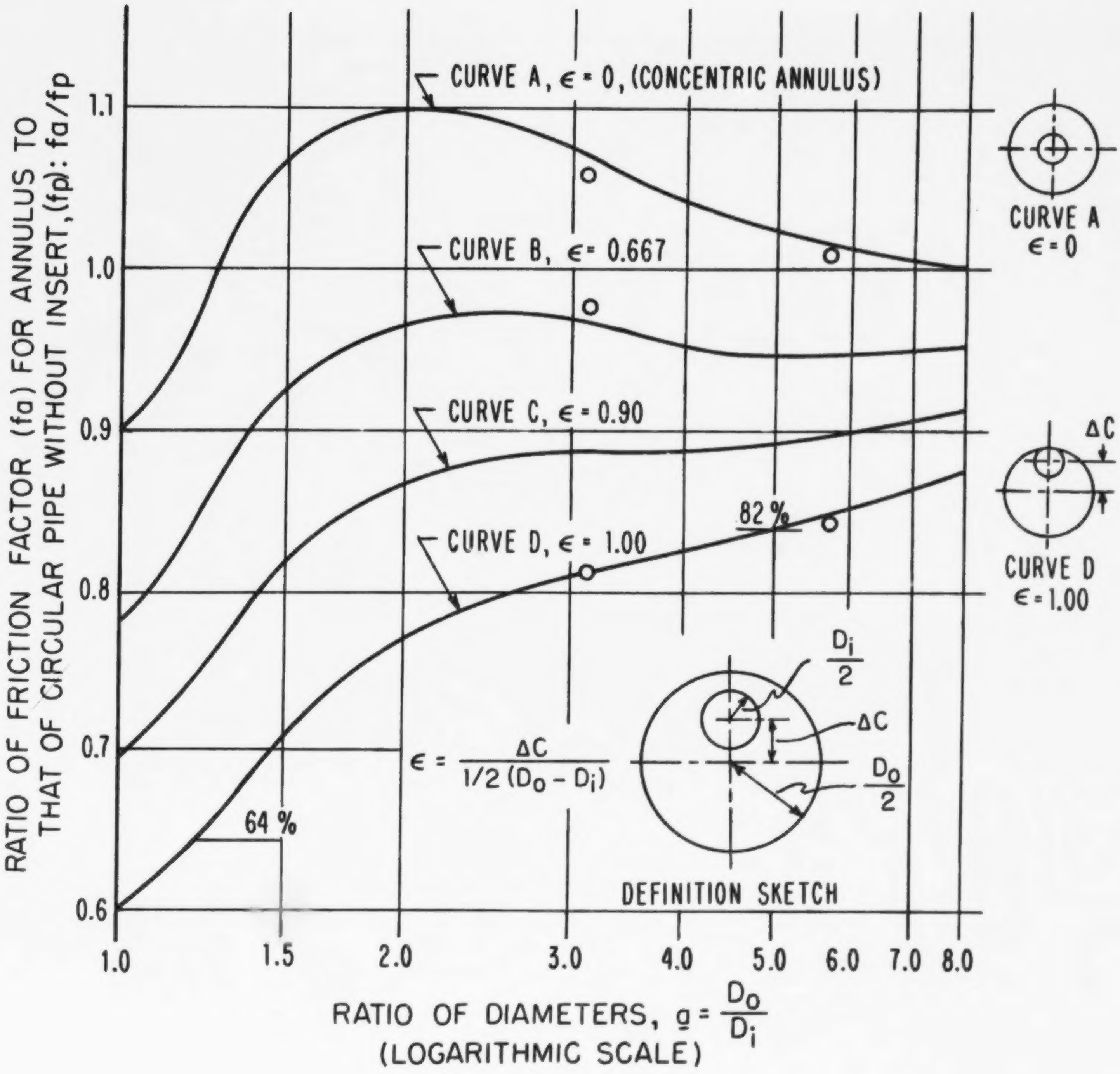


FIGURE 30
DEVIATION OF FRICTION FACTORS FOR CONDUITS OF ANNULAR CROSS-SECTION BASED ON HYDRAULIC RADIUS CONCEPT
(Modified from Fig. 10, Ref. 25)

Flow capacity will be further reduced if the type of pipe hanger employed offers a significant additional obstruction to the flow. The Johns-Manville Company developed a special single-piece molded plastic hanger for the Project (Ref. 24) dimensioned for adequate structural strength with a resultant fairly thick profile at the periphery of the supported pipe. In a hydraulic test of this design at laboratory scale for a pipe diameter ratio, a, of 5.8, flow capacity was 40% less than that for an outer pipe without an inserted smaller pipe. In a trial installation in a combined sewer the field insertion of pipe in this type hanger, subsequent to bonding the hangers in place (Section VII), was found to be awkward and complicated. The main feature of the hanger is its bonding system, and the disadvantages of the original design would be mostly overcome by using an ordinary thin metal strap loop around the inserted pipe, suspended by a rod or rods connected to a molded plastic seat of the original design bonded against the street sewer. That is, installation would be facilitated and hangers would not have an appreciable deleterious effect on flow capacity, over and above that for the inserted pipe. Thus, the indications of the previous paragraph would be reasonably applicable to the revised hanger design.

Maintenance and Operation of Pressure System

As stated in Reference 17, the principal difficulty in a pressure system is believed to be routine maintenance of piping and individual storage-grinder-pump units. Although the anticipated ASCE scheme pressurized sewerage layouts have been provided with a liberal number of cleanout tees, depressuring and cleaning may be attended by numerous difficulties. A gravity sewer can be rodded at any time and still provide service during the cleaning operation. By contrast, a pressure sewer must be closed down during cleaning. All affected storage-grinder-pump units must be turned off, the main must be valved shut, the cleanout tees must be unbolted, and the main must be dewatered. After it has been rodded by conventional means the main must then be resealed and the storage-grinder-pump units must be turned on again.

The required cleaning frequency of pressure sewers cannot be foretold. Because provision would be made in their design for the occurrence of self-cleaning velocities at least once a day, they should need no routine cleaning. However, this surmise will have to be confirmed in practice.

Dewatering a pressure sewer might be a messy and arduous task. A hose valve will conceivably have to be attached to half of the cleanout tees if the pipe is to be dewatered between manholes.

To prevent willful overflows, storage-grinder-pump units will probably not be equipped with an external off-on switch. Some other provision will have to be made to turn the units off for cleaning, repair and maintenance. Night maintenance might be successful.

Cleaning building sewers containing inserted tubing will offer some difficulties. Conventional rodding and root-cutting equipment may be inadequate. Even the larger sized walk-through street sewers in which conduits are suspended at the crown may be difficult to clean with bucket-type drag-through equipment. Pressure water-jet cleaners may work better.

The designer of pressure sewerage must keep in mind the maintenance, repair and replacement of all system components. It may be necessary to provide temporary bypass piping and connections. To speed and simplify the repair of storage-grinder-pump units, they might be replaced in much the same way as water meters have been for many years. Control valve maintenance will include resetting the valves to function within the pressure and flow regime of each particular portion of the system. Careful and complete records of settings would therefore have to be kept. Systems maintenance and repair would probably have to be followed by confirming the operation characteristics of all working parts.

SECTION IX

INTRODUCING PRESSURE SEWER SYSTEMS INTO EXISTING COMBINED SEWER DISTRICTS*

Introduction

The feasibility and cost of the Project scheme were tested for three areas representative of existing combined sewer systems: (1) a central downtown commercial area in Boston, Mass., (2) a mainly residential area in Milwaukee, Wis., and (3) a predominantly residential area in San Francisco, Cal.

Using data supplied by municipal officials and design criteria developed by the ASCE Project, designs of pressurized sewer systems were prepared for the three areas by the Project staff. Under subcontract with ASCE, the three designs were reviewed and evaluated independently by consulting engineers familiar with the study areas. For comparison of the Project scheme with conventional gravity sewer separation, moreover, conventional separation was studied by the consultants for the Boston and Milwaukee study areas and by the San Francisco Department of Public Works for the study area in its jurisdiction.

Brown and Caldwell studied the 323-acre Laguna Street Sewer Service District of San Francisco, Cal. This area is predominantly residential in character with some commercial and a few industrial properties. Most of the structures were built after the 1906 fire. Exclusive of streets, 80% of the area is occupied by buildings. The sanitary sewage is carried to the city's North Point Treatment Plant. Overflows from the combined sewers discharge to San Francisco Bay.

Greeley and Hansen gave their attention to the 157-acre Prospect Avenue Study Area of Milwaukee, Wis. This area is mainly residential but contains scattered institutional or public buildings and small commercial establishments. Originally the area was occupied very densely by small residential structures. Of the single-family residential buildings most were constructed before the late 1930's and a large number even before 1900. Many of them have since been converted to multiple-family use. The dry-weather flow is carried to interceptors near the Milwaukee River and in Brady Street. These discharge to the city's Jones Island Treatment Works. Overflows from the combined sewers discharge to the river.

---

* References 16, 17 and 18.

Camp, Dresser & McKee studied the 53-acre Summer Street Separation Study Area of Boston, Mass. This is a heterogeneous commercial district with closely spaced multi-story office buildings, department stores, and theaters. Many of the buildings date back to the late 1800's. However, a major department store has been added in the last twenty years, and a large apartment and parking-garage building is of recent construction. Dry-weather flow enters the East Side Interceptor of the 1884 Boston Main Drainage System, which has recently been connected to the Deer Island Treatment Plant. Overflows from the combined sewers and the interceptor empty into the Fort Point Channel of Boston Harbor.

Study Areas

Other pertinent characteristics of the three study areas are summarized in Table 14. Location maps and general plans for San Francisco are shown in Figs. 31 and 32, for Milwaukee in Figs. 33 and 34, and for Boston in Figs. 35 and 36.

Separation of Building Plumbing

With the help of plumbing consultants and plumbing and mechanical contractors, the engineering consultants developed the measures needed to separate the sanitary and roof-water drainage piping in the different kinds of buildings of the study areas. Restructuring was based on building surveys and upon data provided by the municipal departments of public works.

Piping to connect the restructured system to gravity and pressure sanitary sewers and to storm drains was identified and cost estimates were made for the different types of plumbing separation required in each class of structure. Layouts were based as closely as possible on local plumbing codes.

The separation of building plumbing is discussed in general in Section X.

San Francisco

As shown in Fig. 37, soil and drain stacks rise separately through the building from the main horizontal building drain in the basement. Traps and vents are required.

Designs and cost estimates were made for separating piping in single-family dwellings, apartment buildings and commercial buildings, as shown in Fig. 38. The principal requirement was an additional main drain and the reconnection of the soil and drain stacks. The cost associated with disruption of normal use of the buildings during their reconstruction was allowed for. The costs of connecting piping to

TABLE 14

CHARACTERISTICS OF STUDY AREAS
HYPOTHETICAL APPLICATIONS OF ASCE COMBINED SEWER SEPARATION PROJECT

	San Francisco, Cal.	Milwaukee, Wis.	Boston, Mass.
Study Area Designation	Laguna Street	Prospect Avenue	Summer Street
Consultant making evaluation	Brown and Caldwell	Greeley and Hansen	Camp, Dresser and McKee
Year for Design	1993 (25-yrs)	1993 (25-yrs)	2020
Extent of gross area (ac.)	323	157	53
Type of development:			
present -	Predominantly residential	Mainly residential	Heterogeneous commercial
projected -	Residential, including highrise	Primarily residential with large apartment complexes	High-rise commercial
Length of combined sewers (ft.)	66,000	33,000	13,000
Topography	Steeply sloping (El. 10 to El. 340)	Gently sloping (El. 30 to El. 80)	Gently sloping (El. 21 to El. 85)
Population	(1960) 21,800	(1966) 11,300 (1993) 14,000	--
Dwelling units ("Housing units")	(1960) 10,900	(1966) 3,500 (est.) (1993) 5,800	--
Annual (winter rate) water use:			
metered -	(1966) 2.97 cfs	(1968) 1.15 cfs	(1968) 1.54 cfs
future -	(1993) 4.78 cfs	(1993) 1.76 cfs	(2020) 3.41 cfs
Number of structures	(1963) 2,773	--	--
Number of service connections	--	(1996) 843	(1968) 600 (200 to be separated)
Special difficulties	Steep slopes	Closely spaced buildings	Narrow streets, subways, crowded utility piping, surcharging at high tide.

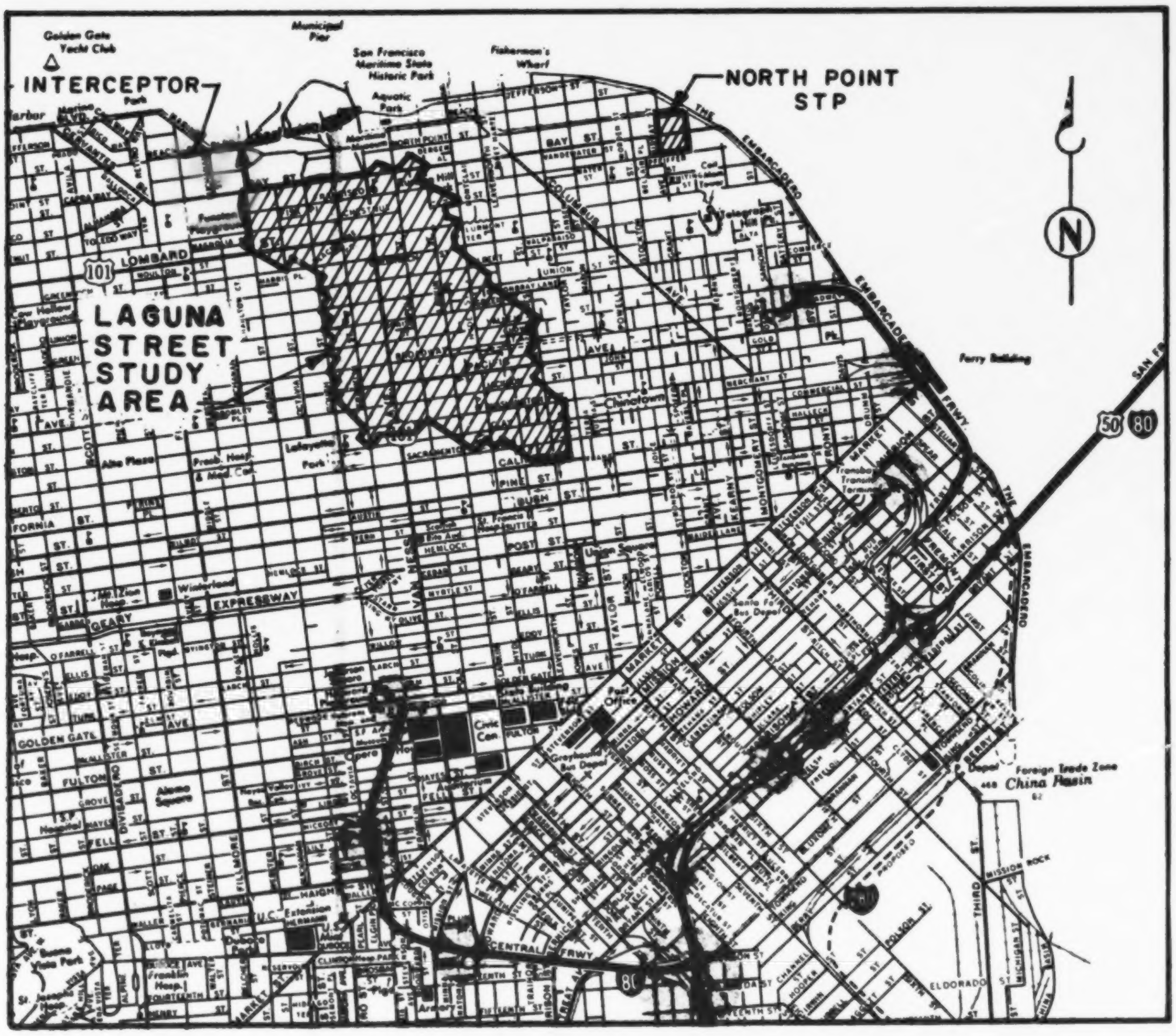


FIGURE 31
LOCATION OF LAGUNA STREET
STUDY AREA, SAN FRANCISCO
(Reproduced from Fig. 2-1, Ref. 16)

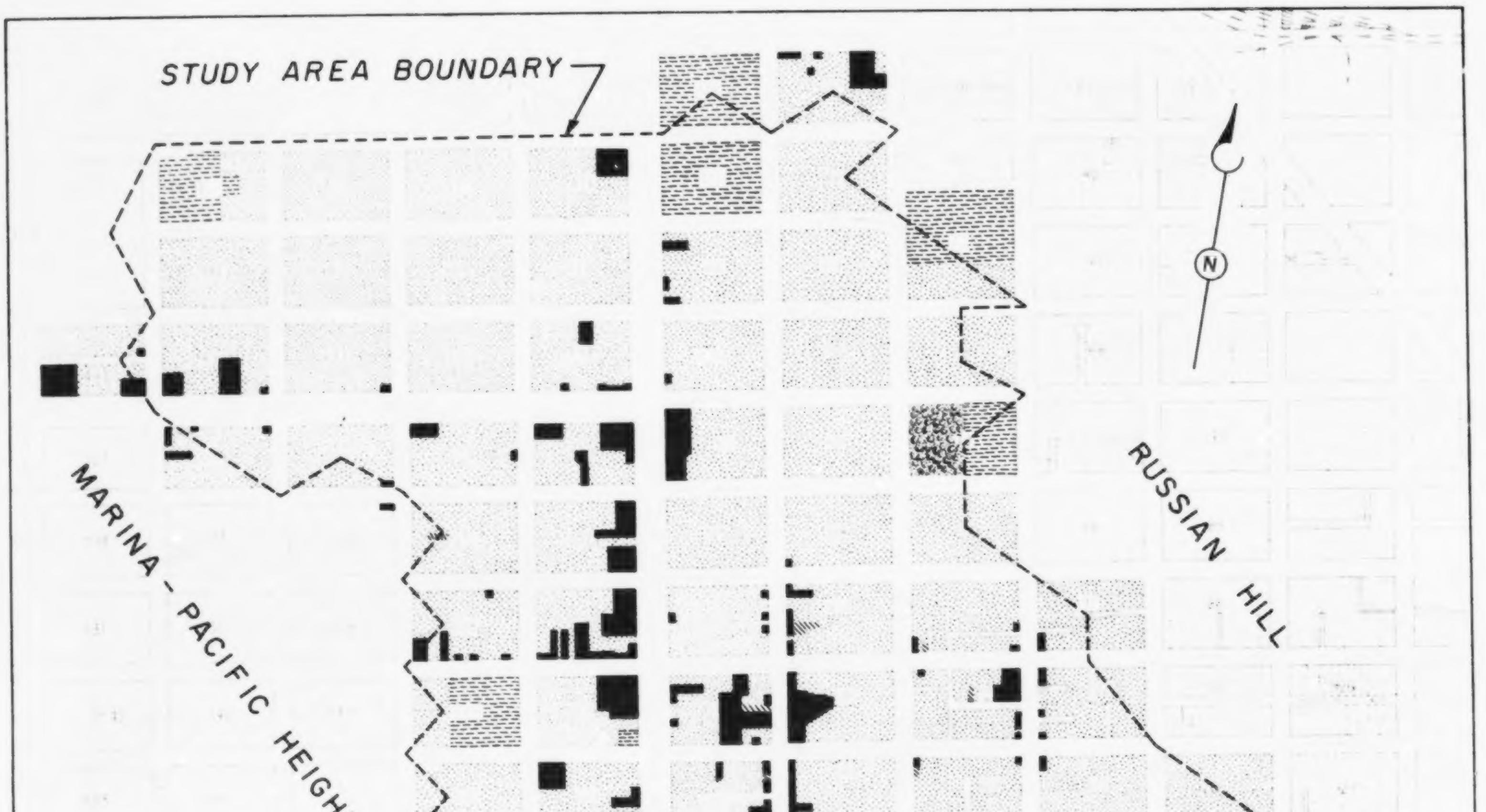


FIGURE 32
BASIC LAND USES IN THE SAN FRANCISCO STUDY AREA
(Adapted from Fig. 2-5, Ref. 16)

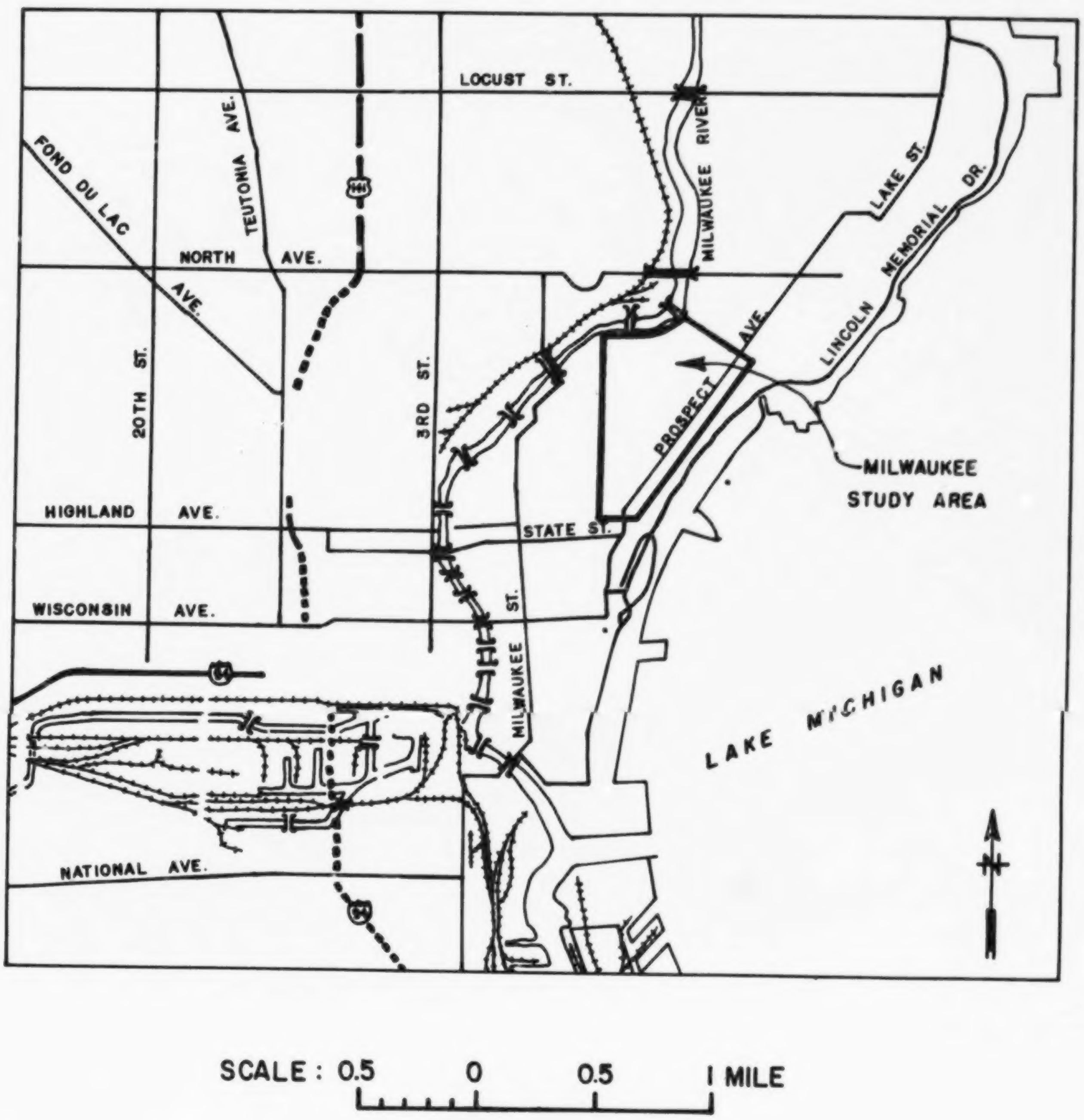


FIGURE 33
LOCATION MAP, MILWAUKEE STUDY AREA
(Reproduced from Fig. 1, Ref. 17)

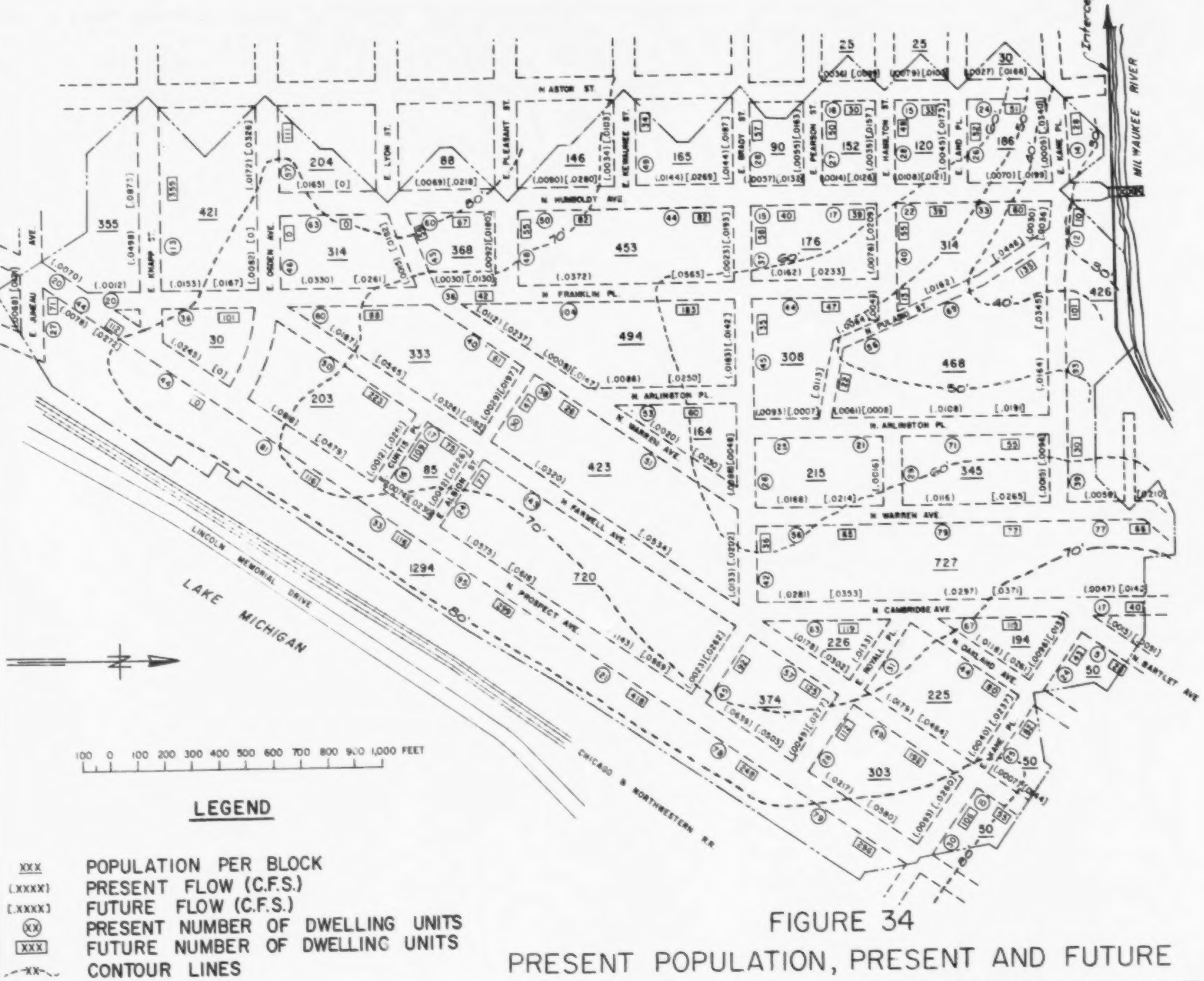


FIGURE 34

PRESENT POPULATION, PRESENT AND FUTURE ESTIMATED FLOW AND NUMBER OF DWELLING UNITS MILWAUKEE STUDY AREA

(Reproduced from Fig. 3, Ref. 17)

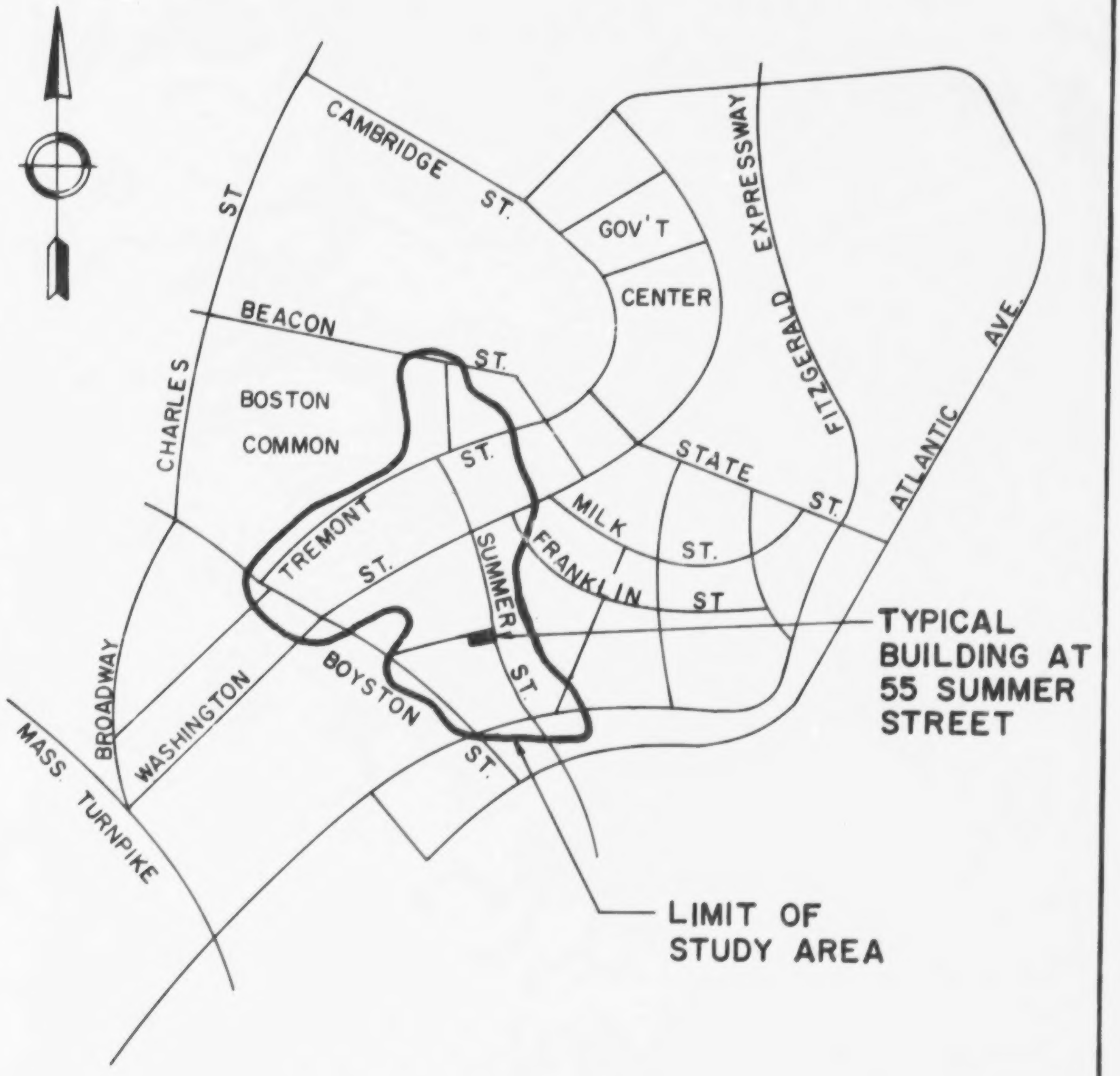


FIGURE 35

LOCATION OF SUMMER STREET SEWER SEPARATION AREA, BOSTON, MASS., AND TYPICAL BUILDING SELECTED FOR STUDY
(Adapted from Fig. IV-1, Ref. 18)

SCALE: 1" = 1000'

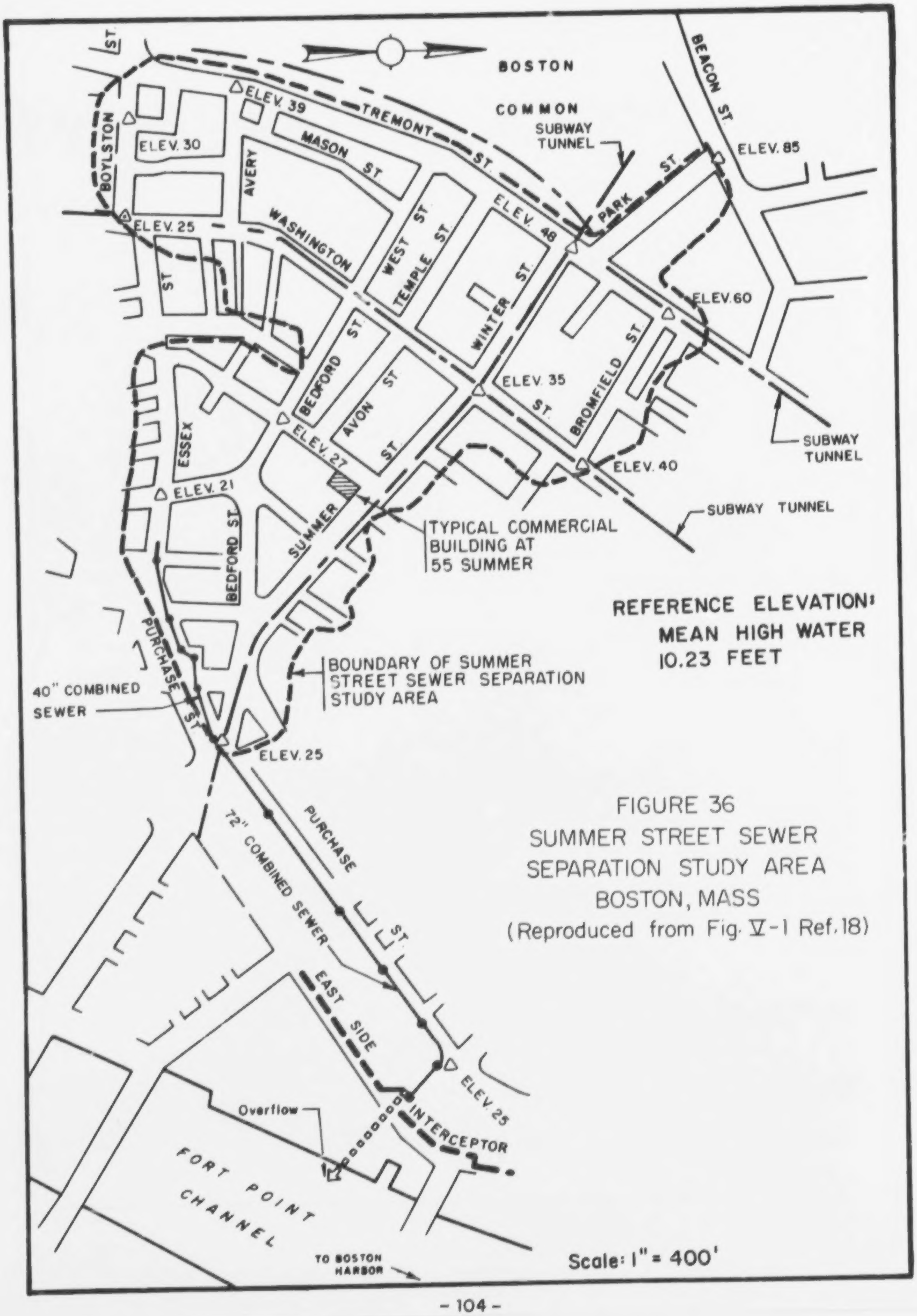


FIGURE 36
SUMMER STREET SEWER
SEPARATION STUDY AREA
BOSTON, MASS
(Reproduced from Fig. V-1 Ref. 18)

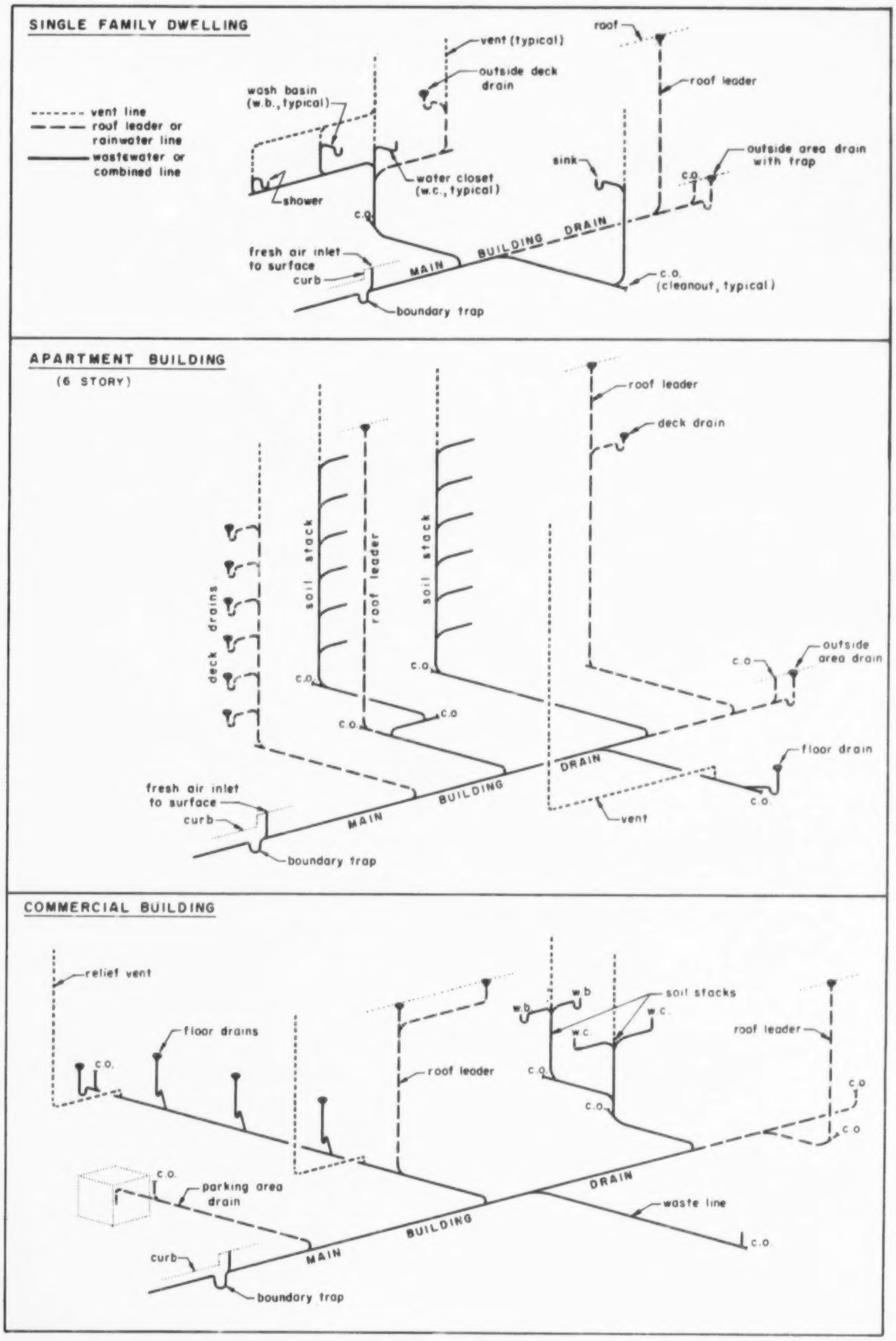


FIGURE 37
TYPICAL IN-HOUSE WASTEWATER AND RAINWATER PLUMBING SYSTEMS, SAN FRANCISCO STUDY AREA
(Reproduced from Fig. 3-1, Ref. 16)

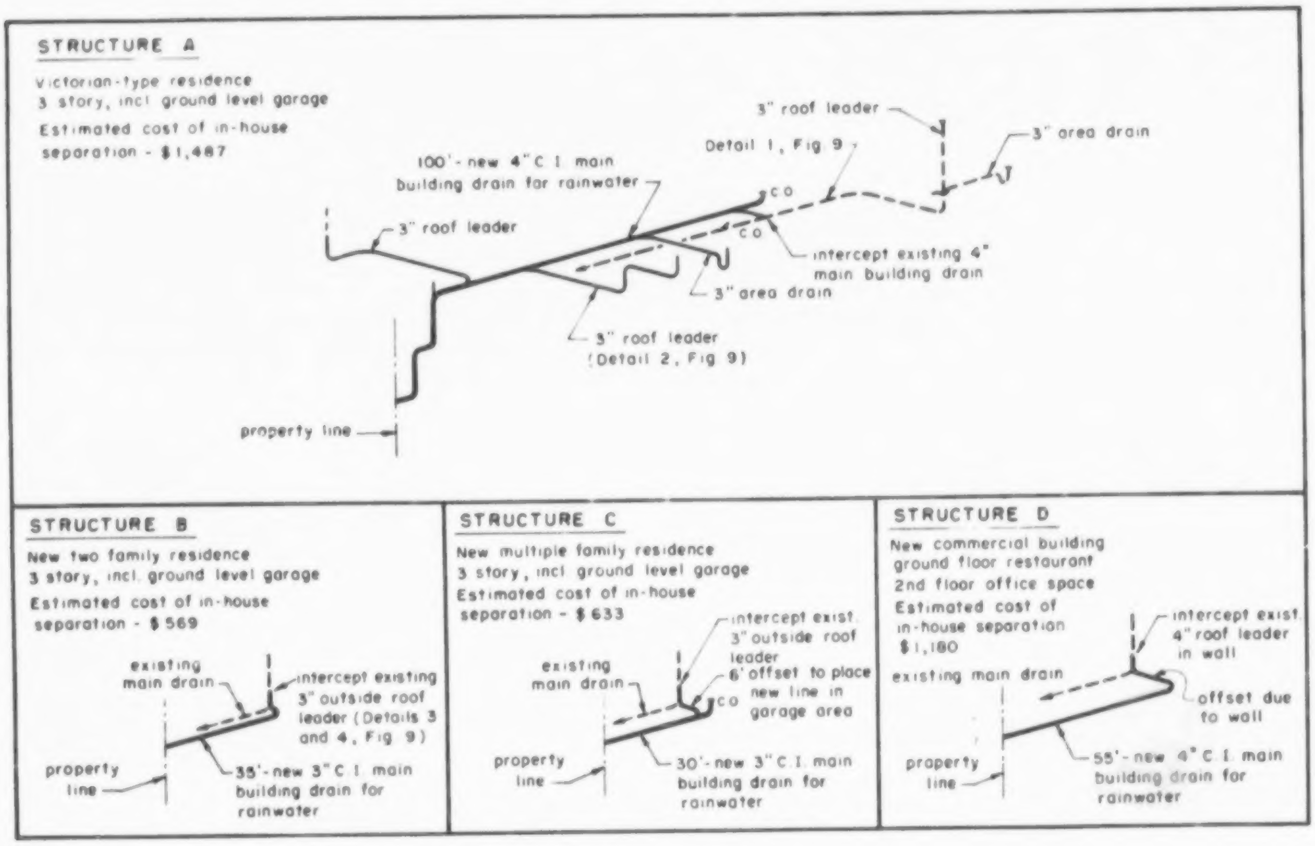


FIGURE 38

PIPING REQUIREMENTS AND ESTIMATED COSTS FOR IN-HOUSE SEPARATION OF SELECTED STRUCTURES, SAN FRANCISCO STUDY AREA

(Reproduced from Fig. 3-3, Ref. 16)

gravity sewers was found to be slightly higher than that for pressure sewers. It was assumed that the conventional building sewer would extend to the front property line, whereas for a pressure sewer system it would terminate at the inlet to the storage tank of the household storage-grinder-pump unit.

Milwaukee

Because the Milwaukee plumbing code formerly allowed all structures on a single building lot to be connected through a single pipe to the combined sewer, separation called for the installation of new sanitary and storm sewers to the street where single pipes had been employed before. Roof drains were generally connected to the main building drain beneath the basement floor. There were no building footing drains in the study area.

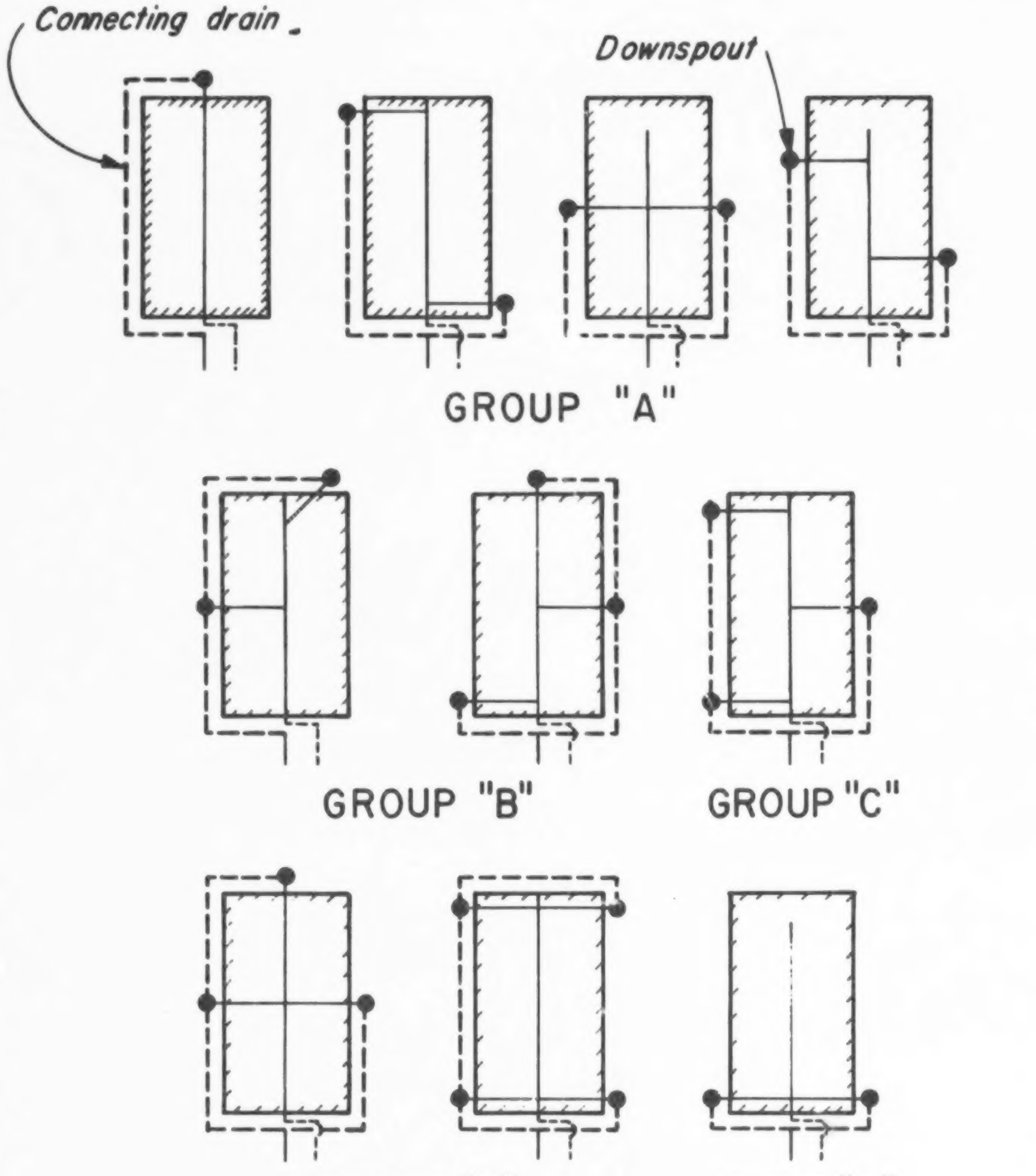
For purposes of design the structures were classified by use, number of floors, type of construction, number of dwelling units and location on the lot. Typical separations were designed for each class, as shown in Fig. 39. It was assumed that new storm drains would have to be laid outside the structures for the collection of roof water but that basement floor drains would not be separated from the existing plumbing.

It was assumed further that the separation of plumbing in the larger buildings would be adapted to their specific requirements and that new storm drains would be laid either along the inside or outside faces of basement walls, whichever was simpler.

Included in the cost of separation for connection to an ASCE pressure system was the line to the street sewer. The cost of the storage-grinder-pump unit itself was made a separate item.

Boston

In the largely commercial Boston study area, where residential structures were restricted to a few buildings with apartments in upper stories, the cost of plumbing separation was estimated for a typical building for which structural and piping plans were available. This five story commercial building, Fig. 40, was constructed in 1892. Connection of the plumbing system to a gravity sanitary sewer lateral and to pressure sewers of the ASCE Project was studied. Typical of Boston buildings is the extension of their basements beneath the sidewalk to the curb line. This reduces the length of the building sewers to the street sewer and storm drain. As shown in Fig. 40, moreover, for a typical building the waste or soil stacks and the roof-water drain stacks extend separately to a junction in the building drain close to the basement wall. The building chosen for study had two service connections to public sewers on intersecting streets, and it was estimated that



NOTE:
Downspouts show minimum number required per group

FIGURE 39
DOWNSPOUT CONNECTION GROUPS
MILWAUKEE STUDY AREA
(Reproduced from Fig. 4, Ref. 17)

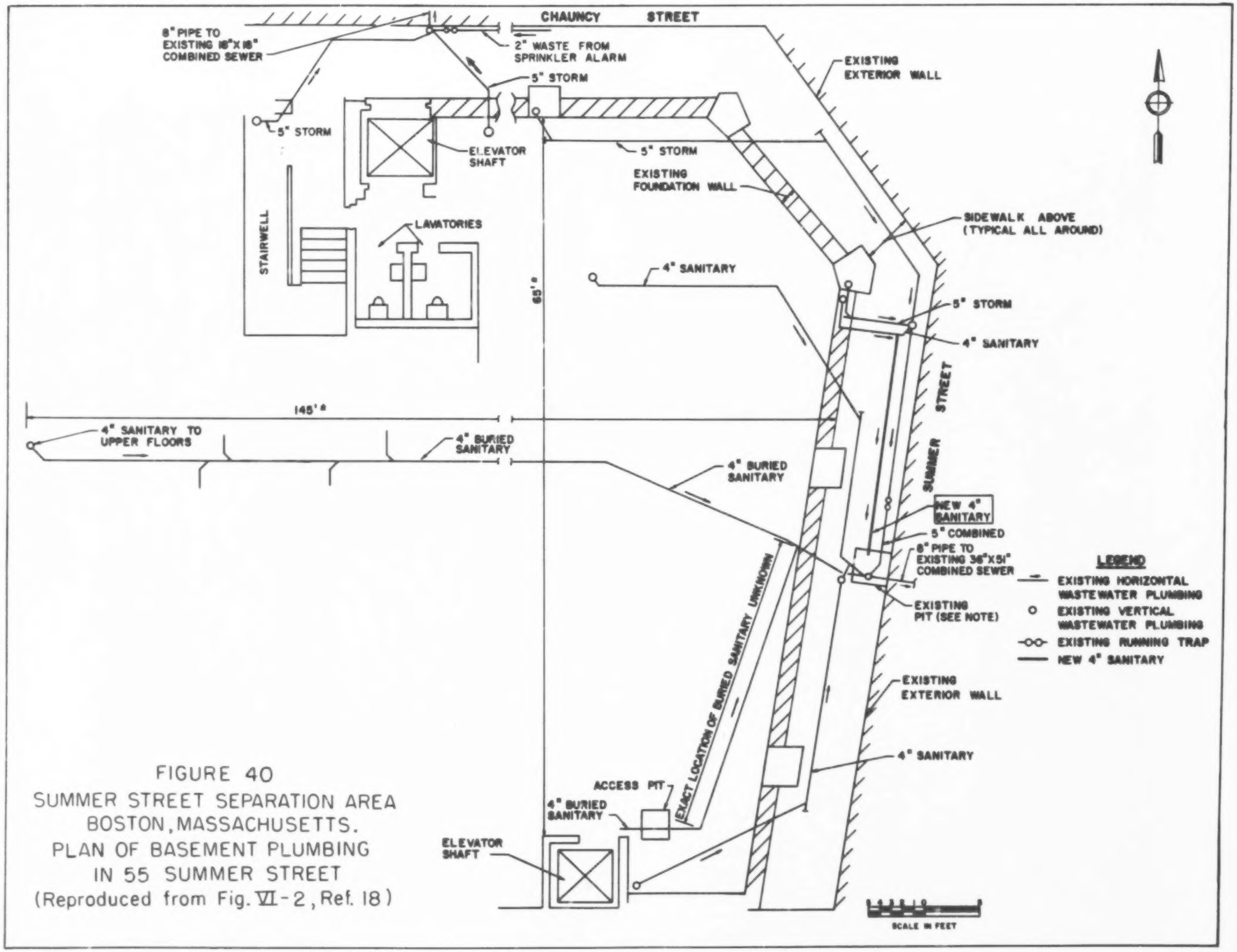


FIGURE 40
SUMMER STREET SEPARATION AREA
BOSTON, MASSACHUSETTS.
PLAN OF BASEMENT PLUMBING
IN 55 SUMMER STREET
(Reproduced from Fig. VI-2, Ref. 18)

only 200 of the approximately 600 recorded building connections to street sewers would require separation. The estimated cost of constructing pits below basement floors and installing comminutors and duplicate pumps was added to that of connections in the item for plumbing separation. A sketch of the suggested pit and pressure piping is shown in Fig. 41.

Summary of Plumbing Separation Studies

A summary of the consultants' information on plumbing separation is presented in Table 15. Estimated costs are given at the bottom of the table.

For San Francisco and Milwaukee, in which the cost of separation does not include the cost of the storage-grinder-pump unit or a functionally equivalent comminutor wet-well pump unit, the cost of building plumbing* separation is about the same for the gravity street system and the pressure sewer system.

Storage-Grinder-Pump Units

The requirements for household and commercial-sized grinding and pumping units, needed volumes of storage, development of the storage-grinder-pump (SGP) unit by the General Electric Company, and the use of comminutors and non-clog sewage pumps are stated in Sections V and VI of this report. It was assumed that the SGP equipment would be applicable to the residential and smaller commercial installations in San Francisco and Milwaukee and that comminutor and non-clog pumps would be installed in the wet-wells of large installations in San Francisco and Milwaukee and of all installations in Boston.

In the Milwaukee study, it was assumed that single-family houses would be served by single SGP units, multi-family houses and small commercial buildings by modified (enlarged) SGP units and larger commercial and industrial buildings by comminutor-pump installations.

In the San Francisco study, the assumption included the use of single SGP units in single- and two-family dwellings; single modified SGP units in small multi-family (3-4 dwelling units) buildings; two or more modified units in large apartment buildings, hotels, and public buildings; and comminutor-pump installations in large commercial and industrial buildings.

---

* With allowance for different lengths of building drains and sewers in San Francisco.

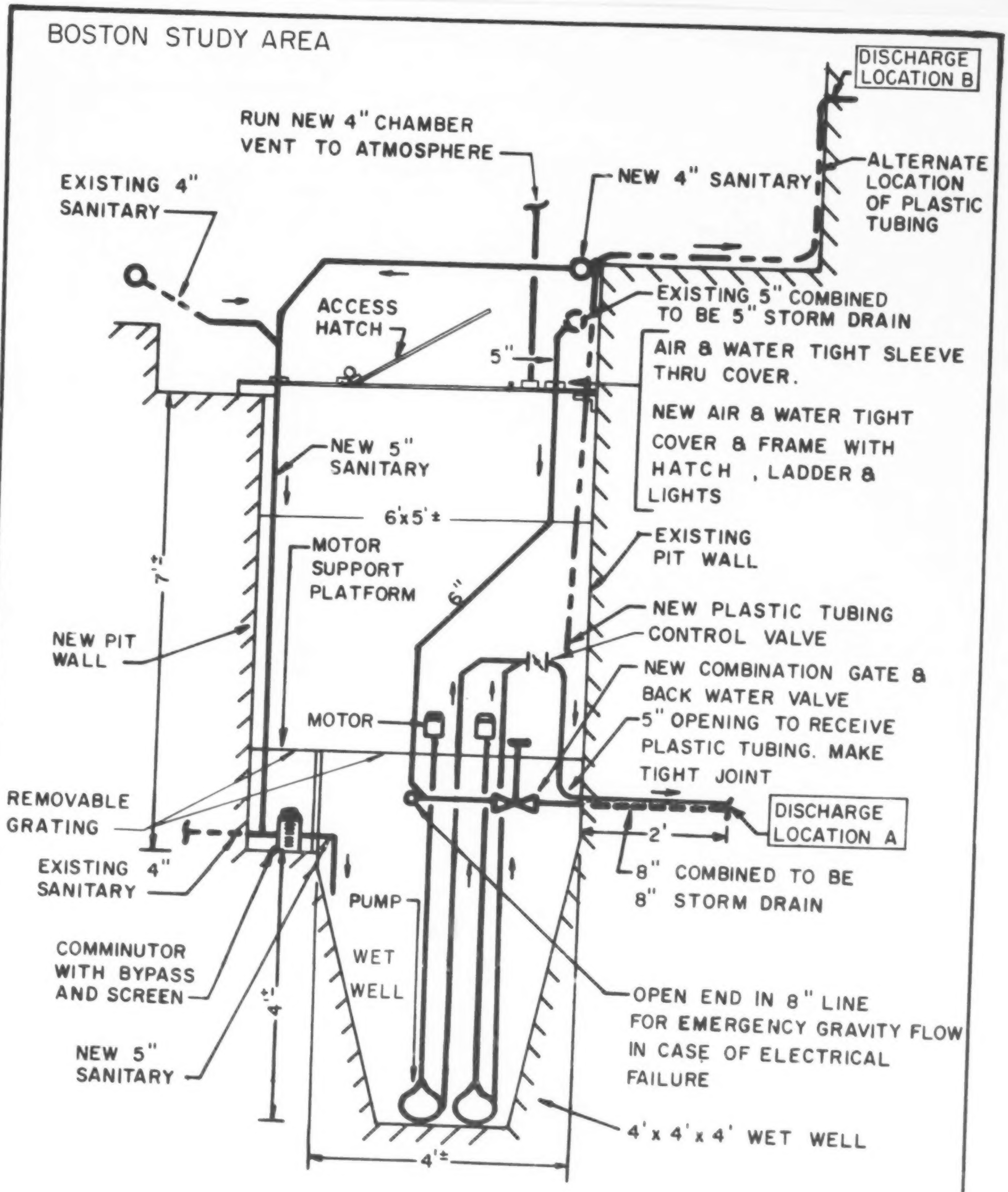

BOSTON STUDY AREA
DISCHARGE LOCATION B
RUN NEW 4" CHAMBER VENT TO ATMOSPHERE
EXISTING 4" SANITARY
NEW 4" SANITARY
ALTERNATE LOCATION OF PLASTIC TUBING
ACCESS HATCH
EXISTING 5" COMBINED TO BE 5" STORM DRAIN
5"
AIR & WATER TIGHT SLEEVE THRU COVER.
NEW AIR & WATER TIGHT COVER & FRAME WITH HATCH , LADDER & LIGHTS
NEW 5" SANITARY
6'x5'±
7'±
MOTOR SUPPORT PLATFORM
6"
EXISTING PIT WALL
NEW PIT WALL
NEW PLASTIC TUBING CONTROL VALVE
NEW COMBINATION GATE & BACK WATER VALVE
MOTOR
5" OPENING TO RECEIVE PLASTIC TUBING. MAKE TIGHT JOINT
REMOVABLE GRATING
DISCHARGE LOCATION A
2'
EXISTING 4" SANITARY
8" COMBINED TO BE 8" STORM DRAIN
PUMP
COMMINUTOR WITH BYPASS AND SCREEN
WET WELL
4'±
OPEN END IN 8" LINE FOR EMERGENCY GRAVITY FLOW IN CASE OF ELECTRICAL FAILURE
NEW 5" SANITARY
4'x 4'x 4' WET WELL
4'±

FIGURE 41
SECTION OF PROPOSED PIT AND PLUMBING, PRESSURE SYSTEM
(Reproduced from Fig. IV-5, Ref. 18)

NOT TO SCALE

TABLE 15

SUMMARY — BUILDING PLUMBING SEPARATION
HYPOTHETICAL APPLICATION OF ASCE COMBINED SEWER SEPARATION PROJECT

	San Francisco, Cal.		Milwaukee, Wis.		Boston, Mass.	
Typical structure	Residential		Residential		Commercial	
Age of structure	Since 1906		Prior to 1930		Late 1800's	
Number of building service connections	2773		843		200	
Plumbing code controls	Yes		Yes		Yes	
Roof drains connected separately to junction in basement	Yes		Yes		Yes	
Average cost of plumbing separation including engineering and contingencies	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity
Per building, not including SGP unit	$1,590(1)	$1,950(2)	$1,440(3)	$1,350(3)	--	--
Per building, including SGP and connections	#3,500	$2,300	$3,100	$1,350	$20,000	$10,000

(1) Connection as far as SGP unit

(2) Connection as far as front property line

(3) Connection to lateral

Building Service Connections

Two principal alternative arrangements of building service connections were studied. In one of them, as in Professor Fair's original scheme, the pressure tubing was inserted in the existing building drain and sewer for the full distance to the existing street sewer. In the other arrangement, pressure tubing was laid below frost depth in a trench leading from the building to a pressure conduit in trench near the sidewalk. These alternative schemes are described and summarized in Section VII.

Because of the difficulty of inserting pressure conduits in small combined sewers, which predominated in the study areas, cost estimates were based on adoption of the second scheme.

Pressure Sewer Systems

The ASCE Project method for separation by pressure pipes leading from storage-grinder-pump units to pressure conduits in the street was applied by the ASCE Project staff to each study area and the resulting designs were reviewed and accepted as reasonable by the consultants.

Sewage Flow Rates

Design criteria for pressure sewer systems are reported in some of the Technical Memoranda prepared by the ASCE Project staff. Flow rates are summarized in Section IV.

For maximum and minimum conduit sizing, rates of flow are generally based on the average annual domestic water demand, multiplied by a factor reflecting the number of dwelling units or services tributary to the reach of conduit under consideration. The factors are shown in Figs. 6 and 7. Those in Fig. 6 are for the northeastern United States and were assumed to be applicable to the Milwaukee study area, and those in Fig. 7 were assumed to be applicable to the San Francisco study area.

Annual domestic water demands considered representative of sewage flows were taken from records of measured winter water use for the San Francisco and Milwaukee study areas.

Design periods assumed for San Francisco and Milwaukee are 25-years, and for Boston 50-years.

Conduit Materials

Suitable pipe-within-a-pipe tubing for building drains and sewers and for pipe conduits in street sewers were identified by the National Sanitation Foundation (Ref. 23). Tubing could be copper, or polyethylene or polybutylene plastic such as that employed in domestic water service-connections 1¼-in. to 2-in. in diameter. Conduits could be asbestos-cement, cast iron, ductile iron, coated steel, or plastic pipes, 2-in. through 18-in. in diameter.

Hydraulic Criteria

Basic hydraulic criteria for the design of piping systems, including the choice of pipe sizes for different ranges of flow and the preservation of reasonable hydraulic gradients within available pumping heads and horsepower ratings are discussed and illustrated in Section VII.

Service Districts and Pressure Zones

A service district is defined as a section of a pressurized sanitary sewer system that is hydraulically independent of an interceptor and adjacent service districts. Such a district has definable boundaries and discharges its sanitary sewage into an interceptor for transport to a treatment plant. It would necessarily be treated as a complete unit and provide for the separation of all the combined sewers it contains. A pressure zone is defined as a subdivision of a service district separated from the remainder of the district by a pressure-control valve.

Alternative Arrangements of Collection Systems

Six alternative arrangements of pressurized sewerage schemes were presented in the report of the National Sanitation Foundation (Ref. 23). They are summarized and discussed in Section VII. Of these arrangements, three were used in alternative designs reviewed by the engineering consultants to establish the probable cost of constructing pressurized systems. These three are identified as Layouts A, D and nSf in Figs. 20, 24, and 25, respectively.

Layouts A and nSf are relatively conservative in nature. Each includes dual-main pressure conduits as well as dual laterals. Street valves isolate block-long runs of mains to permit maintenance and repair without shutting down large portions of the system. Although the resultant partially duplicative piping might appear extravagant, it was the opinion of the engineering consultants that this made for a reasonable and safe substitute for gravity separation of sewers.

If methods of cleaning pressure conduits in lengths greater than about 500-ft. can be developed and confirmed, fewer street valves and valve manholes would be required than assumed in the cost estimates, which should substantially reduce the costs for these components.

Layout Studies

As explained earlier in this section, alternative systems designed by the ASCE Project staff were reviewed and their costs estimated by engineering consultants. These studies are summarized immediately below.

San Francisco

For the San Francisco study area, two alternative arrangements of pressurized sewers were chosen. Alternative A established an essentially dendriform (branching) pattern of sewerage in which individual branches consist of parallel conduits on the sides of each street. Interconnections at street intersections would provide some manifolding and duplex available paths. Alternative A, based on Layout A in Section VII (Fig. 20), is shown in Figs. 42 and 43. Pressure conduits were not placed inside existing combined sewers.

As shown in Fig. 44, a profile with hydraulic gradients for the main sewer, five pressure zones separated by pressure control valves were necessary to care for existing differences in ground elevation.

Alternative B would be similar in design except that pressure conduits would be suspended from the crown of combined sewers of walk-through size. Use of pressure conduits suspended in existing sewers would thereby be restricted to the reach of trunk sewers downstream from Broadway and Franklin Streets, Fig. 42. The resulting layout would be similar to Layout D of Section VII (Fig. 24).

Although field tests have shown that in the absence of obstructions tubing can be inserted in building drains and sewers as far as the street sewers, where the tubing could be connected to a pressure conduit within the street sewer if it is of working height, this would be complicated in San Francisco by the presence of a plumbing trap located in each building service connection at the line of curb or sidewalk or immediately inside the wall under the sidewalk, as called for in the plumbing code. With separation via a pressure system there would no longer be a need for the trap and it could be removed and replaced by a straight section if the plumbing code was amended accordingly. Tubing could then be inserted in building drains and sewers as far as the street sewer. However, for study purposes it was assumed that the trap would not be removed and that tubing would be installed in a trench leading from the basement to small auxiliary conduits in trenches on each side of the street, which in turn would be connected to the conduit within the existing sewer at street intersections.

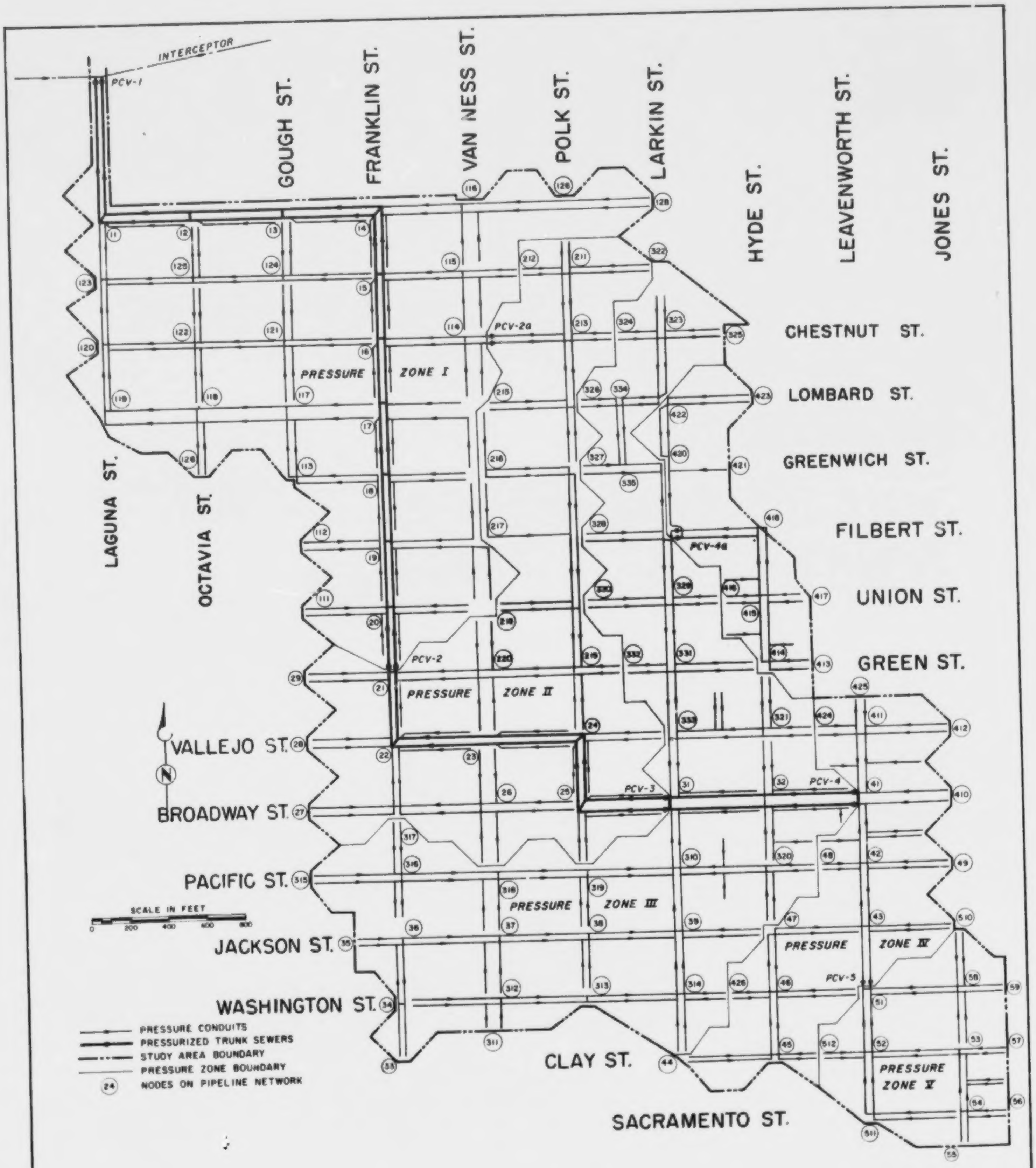
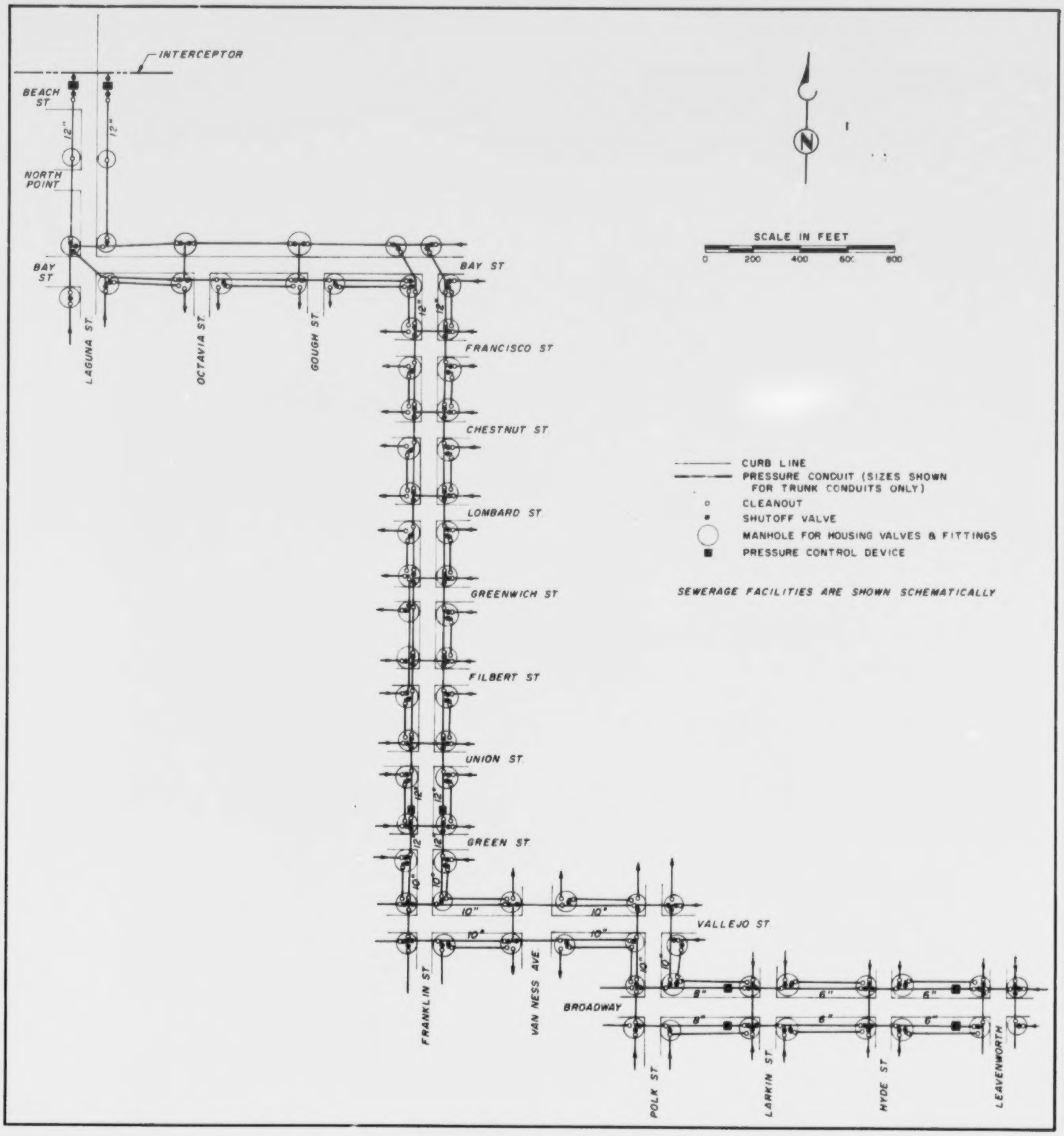


FIGURE 42
PRESSURE SEWER SYSTEM LAYOUT-ALTERNATIVE A,
SAN FRANCISCO STUDY AREA
(Reproduced from Fig. 5-4, Ref. 16)



SEWERAGE FACILITIES ARE SHOWN SCHEMATICALLY

FIGURE 43
DETAILS OF TRUNK SYSTEM - ALTERNATIVE A, SAN FRANCISCO STUDY AREA
(Reproduced from Fig. 5-5 of Ref. 16)

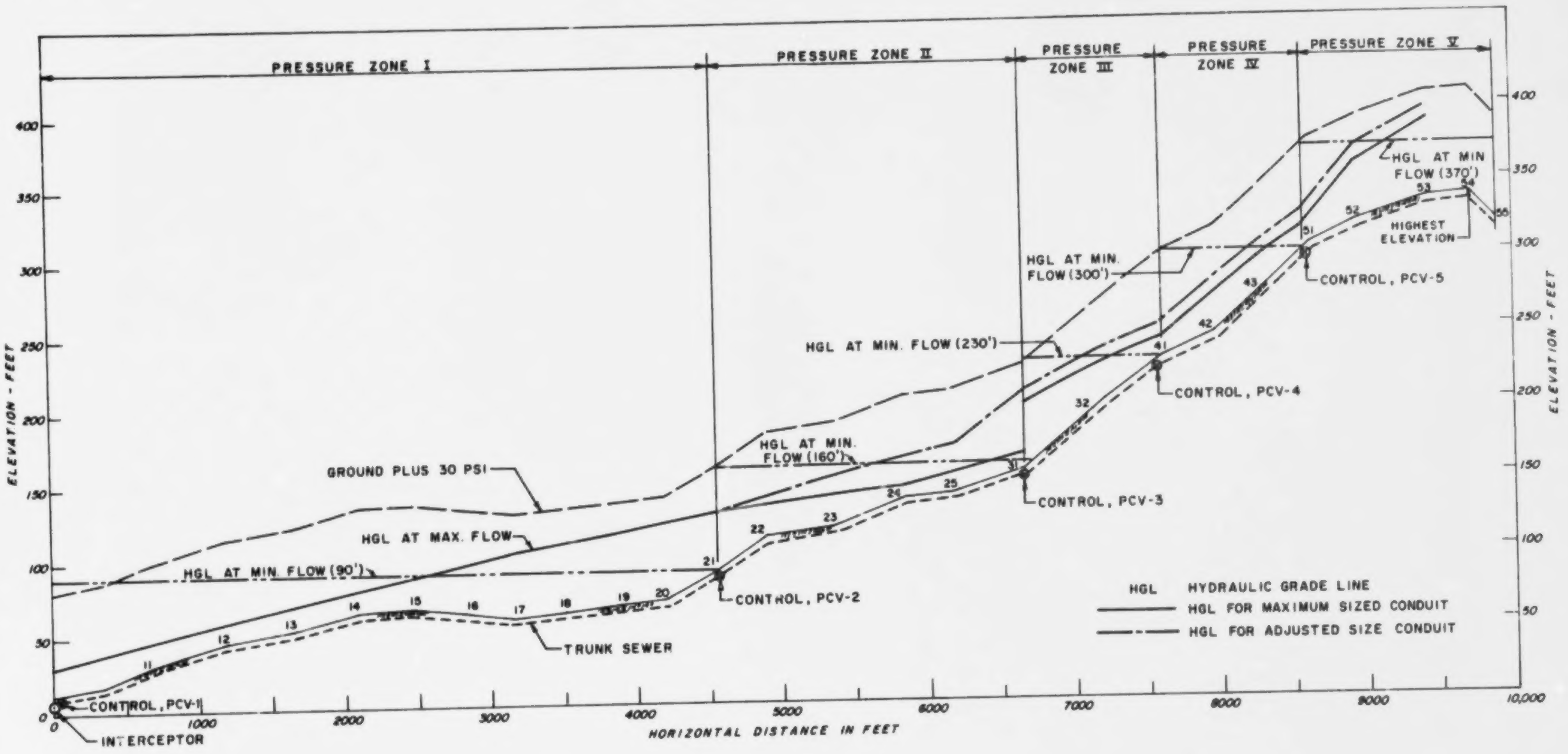


FIGURE 44
PROFILE OF PRESSURE SEWER SYSTEM-ALTERNATIVE A, SAN FRANCISCO STUDY AREA
(Reproduced from Fig. 5-7, Ref. 16)

A drawing of Alternative B would be similar to that of Alternative A in the arrangement of conduits, cleanouts and valves. The nSf Layout (Fig. 25 of Section VII) was considered but not used because of marginal applicability.

A design of gravity sewers by the San Francisco Department of Public Works for the conventional separation of sewers in the combined-sewer area is shown in Fig. 45. The engineering consultants accepted this design for their cost estimates.

Milwaukee

At Milwaukee, two alternative pressure systems of separation were studied along with a conventional gravity scheme. Milwaukee pressure sewerage Layout M-1 based on Layout A of Section VII is shown in Fig. 46 as a dendriform system in which dual pressure lines are placed on the sides of each street. The dual conduits in each street are cross-connected at every street intersection. The study area is flat enough to lie in a single pressure zone.

Milwaukee Layout M-2, Fig. 47, is based on the nSf Layout, Section VII. As stated there, the nSf Layout is the most flexible one. It comprises a reticular or latticed network structure, including dual conduits cross-connected at each cross-street. The resulting parallel grid allows the sewage to bypass a blockage or a valved-off zone of the system. However, it might increase the residence time of the sewage within the system and cause some stagnation because flows would be free to follow paths of least resistance and cause some elements of the system to carry little sewage. The service district lies in a single pressure zone, upstream of pressure control valves at the interceptor.

The two alternative arrangements call for placing conduits in separate shallow trenches. None would be inserted in existing sewers. Less than 6% of the length of the combined sewers in the study area is composed of 54-in. or larger sewers and only 8.6% of 48-in. or larger sewers. The ASCE Project staff considers a 54-in. sewer the smallest suitable as a walk-through structure in accordance with the 1967 report of the Portland Cement Association to the Project (Ref. 4). The lack of long runs of walk-through sewers in suitable locations precluded the use of inserted conduits in the Milwaukee study.

A conventional gravity alternative arrangement, Layout M-Gr, which is shown in Fig. 48, was used as a basis of cost estimate for comparison with cost estimates for Layouts M-1 and M-2.

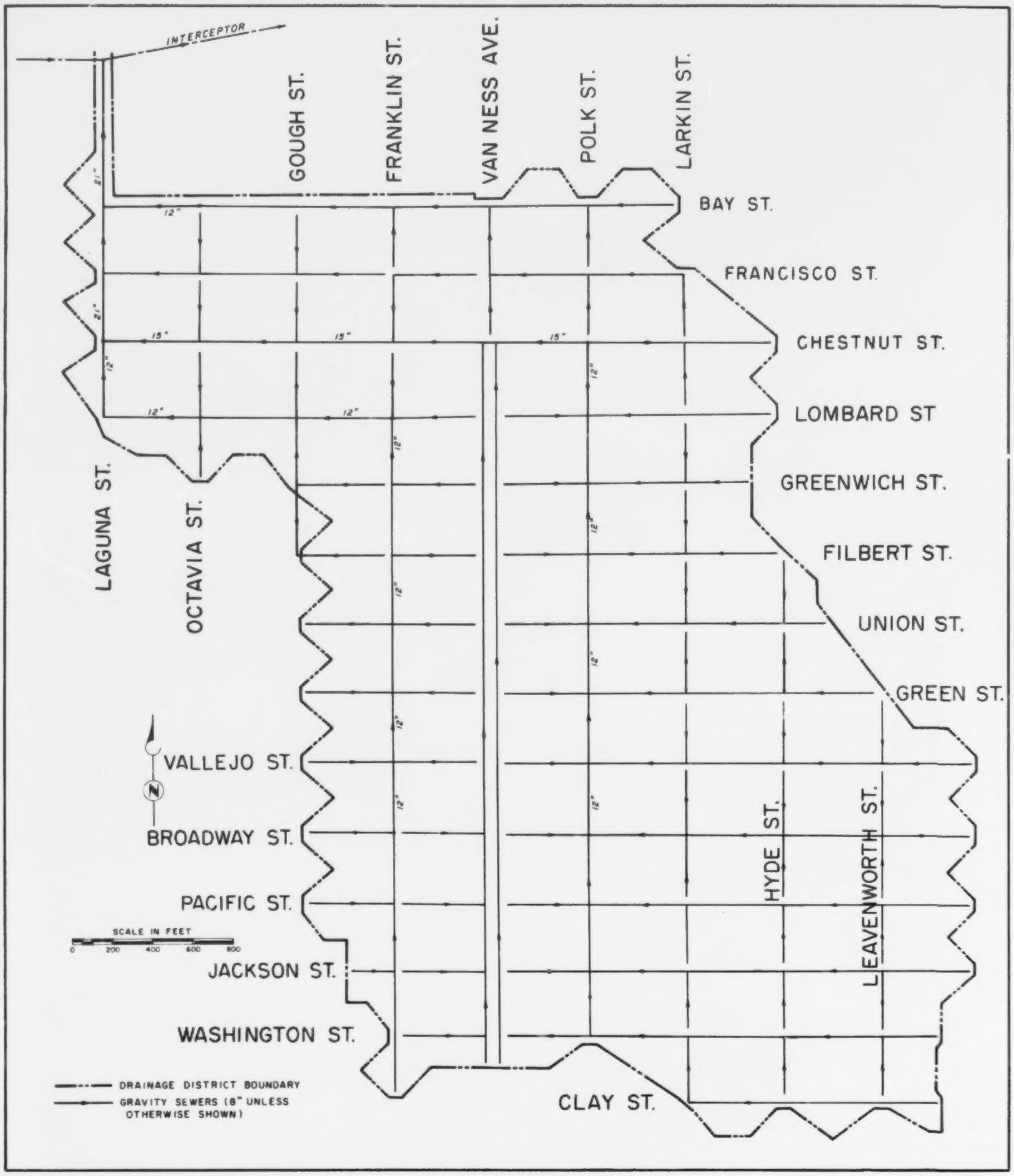


FIGURE 45

GRAVITY SEWER SYSTEM LAYOUT, SAN FRANCISCO STUDY AREA

(Reproduced from Fig. 4-1, Ref. 16)

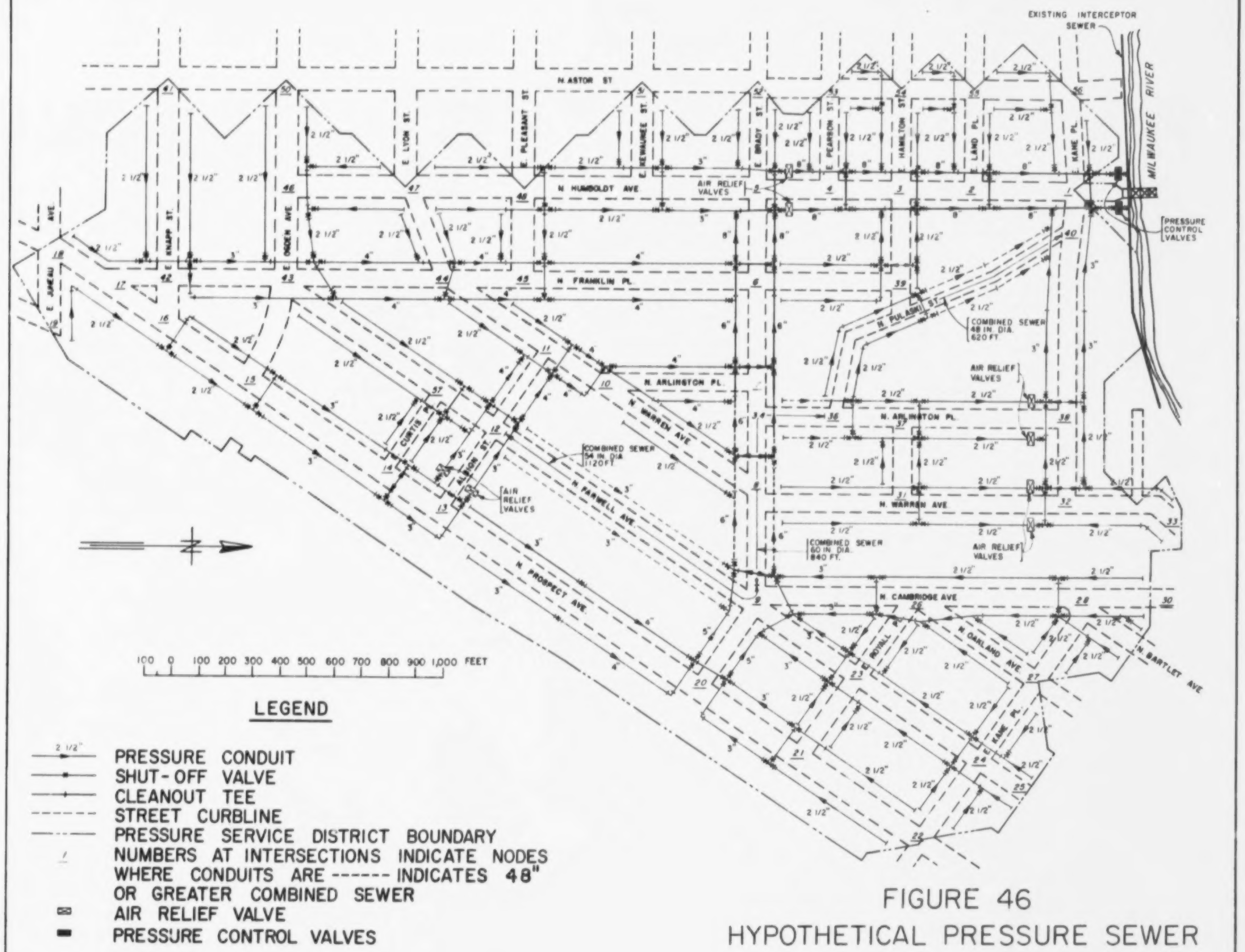


FIGURE 46
HYPOTHETICAL PRESSURE SEWER
SYSTEM LAYOUT M-1
MILWAUKEE STUDY AREA
(Reproduced from Fig. 9, Ref. 17)

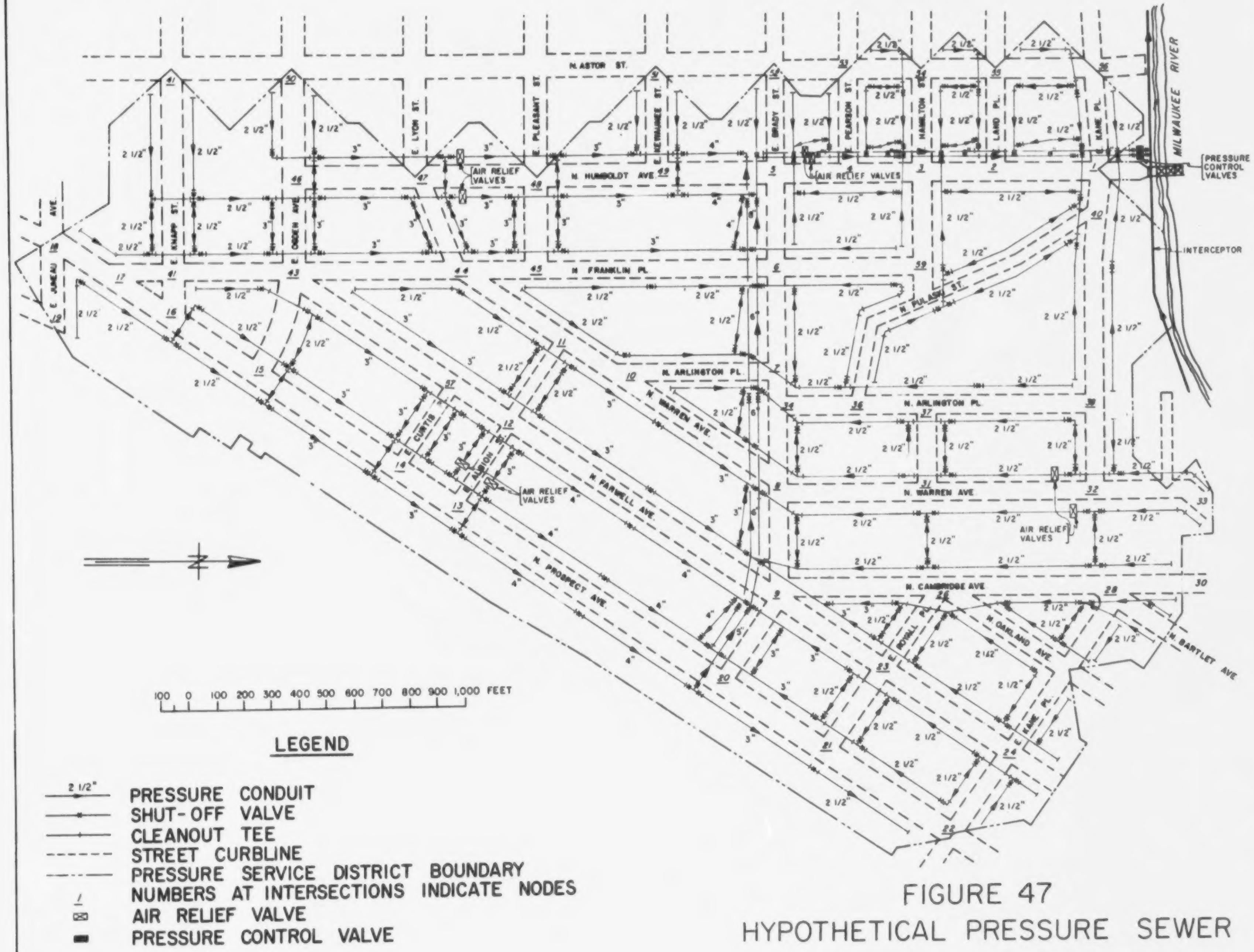


FIGURE 47
HYPOTHETICAL PRESSURE SEWER
SYSTEM LAYOUT M-2
MILWAUKEE STUDY AREA
(Reproduced from Fig. 11, Ref. 17)

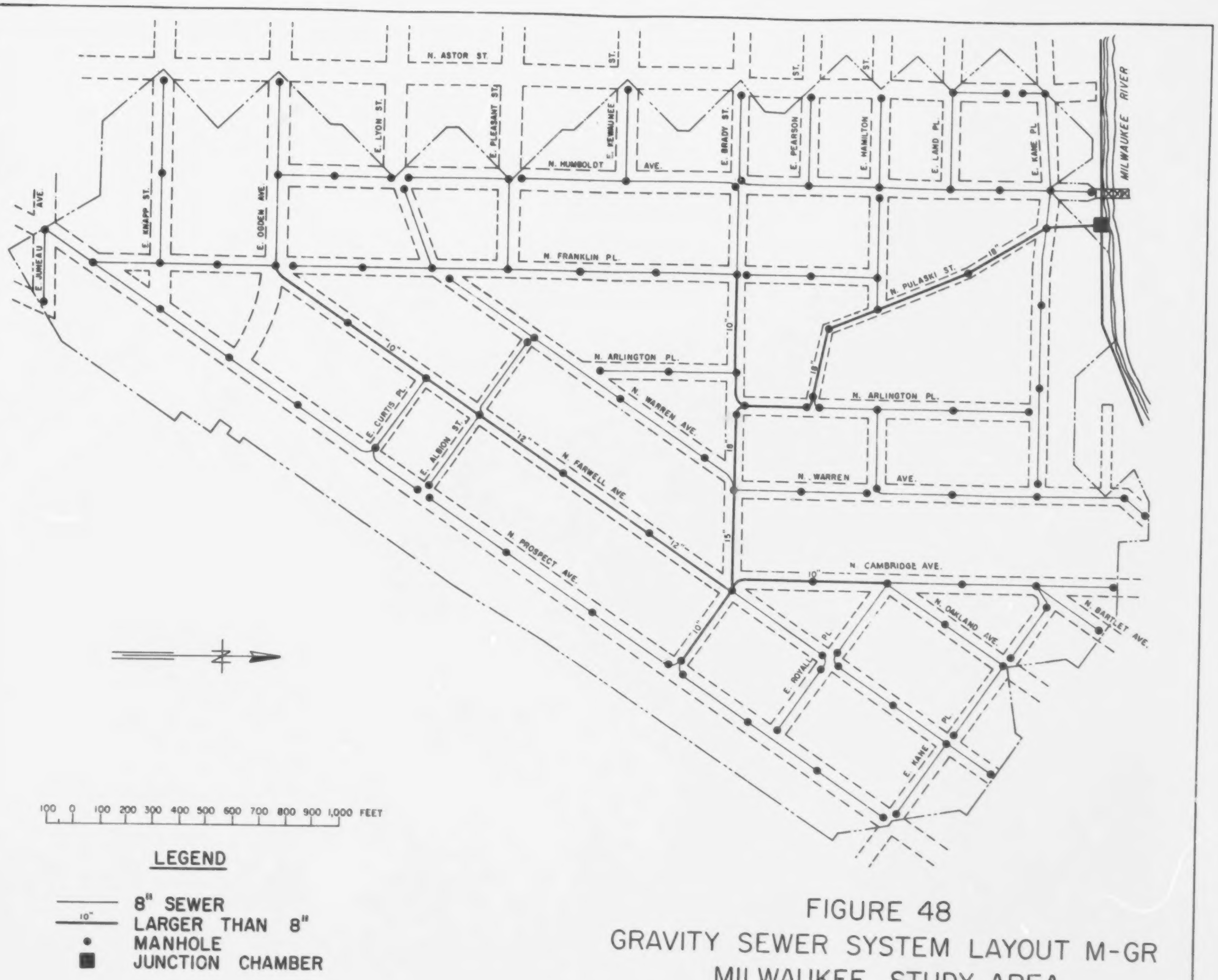


FIGURE 48
GRAVITY SEWER SYSTEM LAYOUT M-GR
MILWAUKEE STUDY AREA
(Reproduced from Fig. 12, Ref. 17)

Boston

At Boston, the physical arrangement of the pressure sewer system was studied in terms of Layout A of Section VII because this layout seemed to fit the branching pattern of existing streets better than the nSf Layout. The three alternative designs developed differed only in the extent to which in-line pumps and controls were assumed to be incorporated in the scheme.

Design I, Fig. 49, employs no pumps other than those in the building basements. The system lies within two pressure zones and is controlled by pressure valves, one pair at the interceptor and two pairs at Winter and Washington Streets. This arrangement is possible because the area is fairly flat. Requisite pipe sizes are indicated in Fig. 49.

Alternative designs were prepared to evaluate the advantages of in-line pumping to produce steeper hydraulic gradients and permit use of correspondingly smaller pipes and higher minimum velocities. The minimum velocity downstream of an in-line lift-station pump is fixed by the discharge rate of the smallest station pump operating alone. As shown in Design II, Fig. 50, which includes a single in-line lift-station, most of the pressure trunk conduits could be reduced by one pipe size below those in Design I, were it not for the fact that the elevated hydraulic grade line of the trunk sewer requires the allowable gradients of branches within the reach downstream of the pumping station to be flatter. In some instances, larger pipes might be required for such branches.

Design III, Fig. 51, incorporates three lift-stations on the trunk conduit in order to reduce the elevation of the hydraulic grade line downstream of the single-lift pumping station of Design II. Design III requires pipes of smaller diameter than many of the corresponding pipes in Design I and does not require branch pipes as large as those in Design II. However, Design III requires more pumping stations and more complex pump and pressure controls.

Conventional gravity separation of the combined sewers in the Boston study area had been studied by the engineering consultants prior to their being engaged for the ASCE Project. Associated cost estimates were available for comparison with those of the pressure scheme. No illustration of the gravity separation is included in this report.

Estimates of Annual Costs, Milwaukee Study Area

Annual costs, including operating cost and amortization of the cost of construction, were evaluated for the three alternative Milwaukee designs by the engineering consultants and are presented for comparison in Table 16.

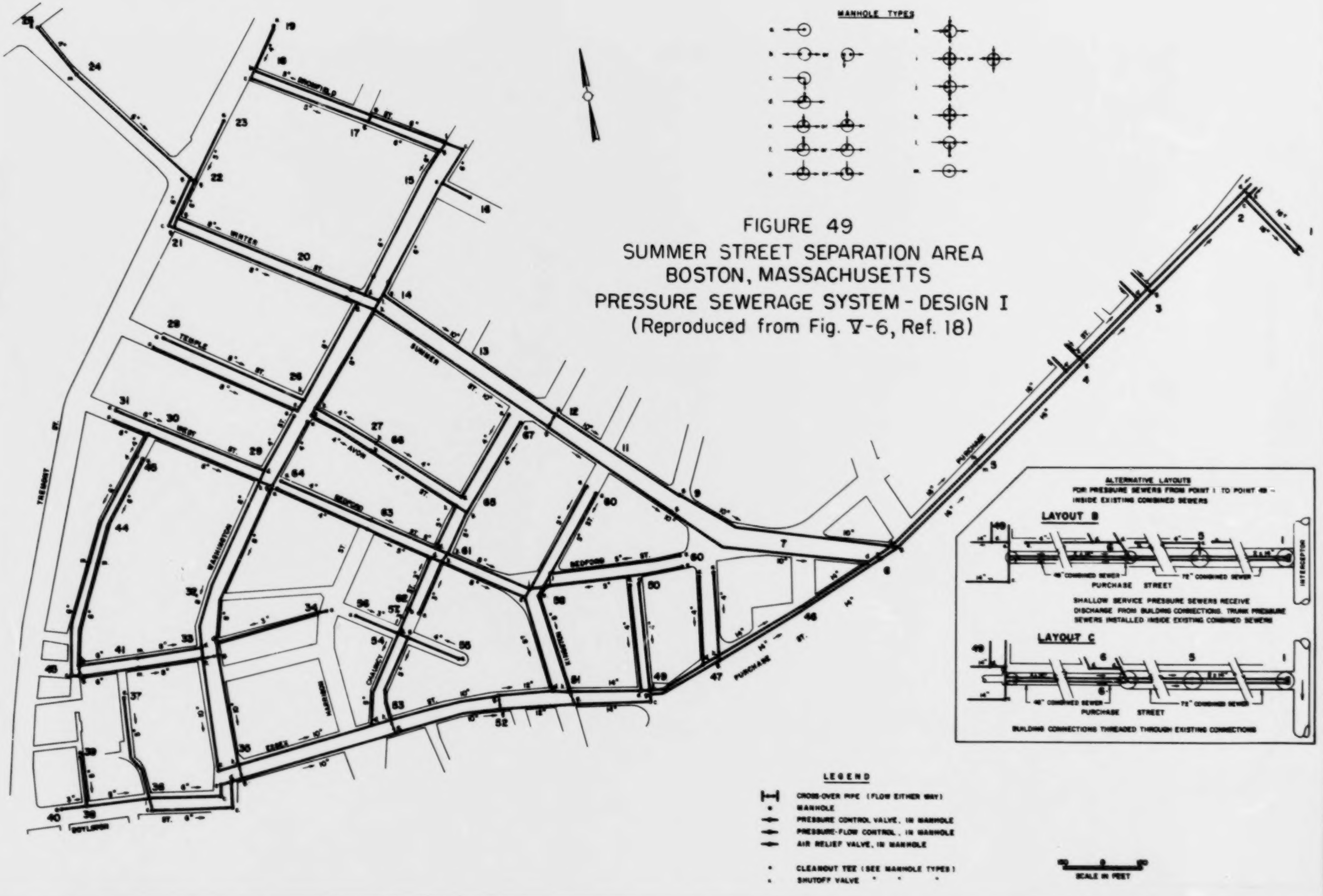


FIGURE 49
SUMMER STREET SEPARATION AREA
BOSTON, MASSACHUSETTS
PRESSURE SEWERAGE SYSTEM - DESIGN I
(Reproduced from Fig. V-6, Ref. 18)

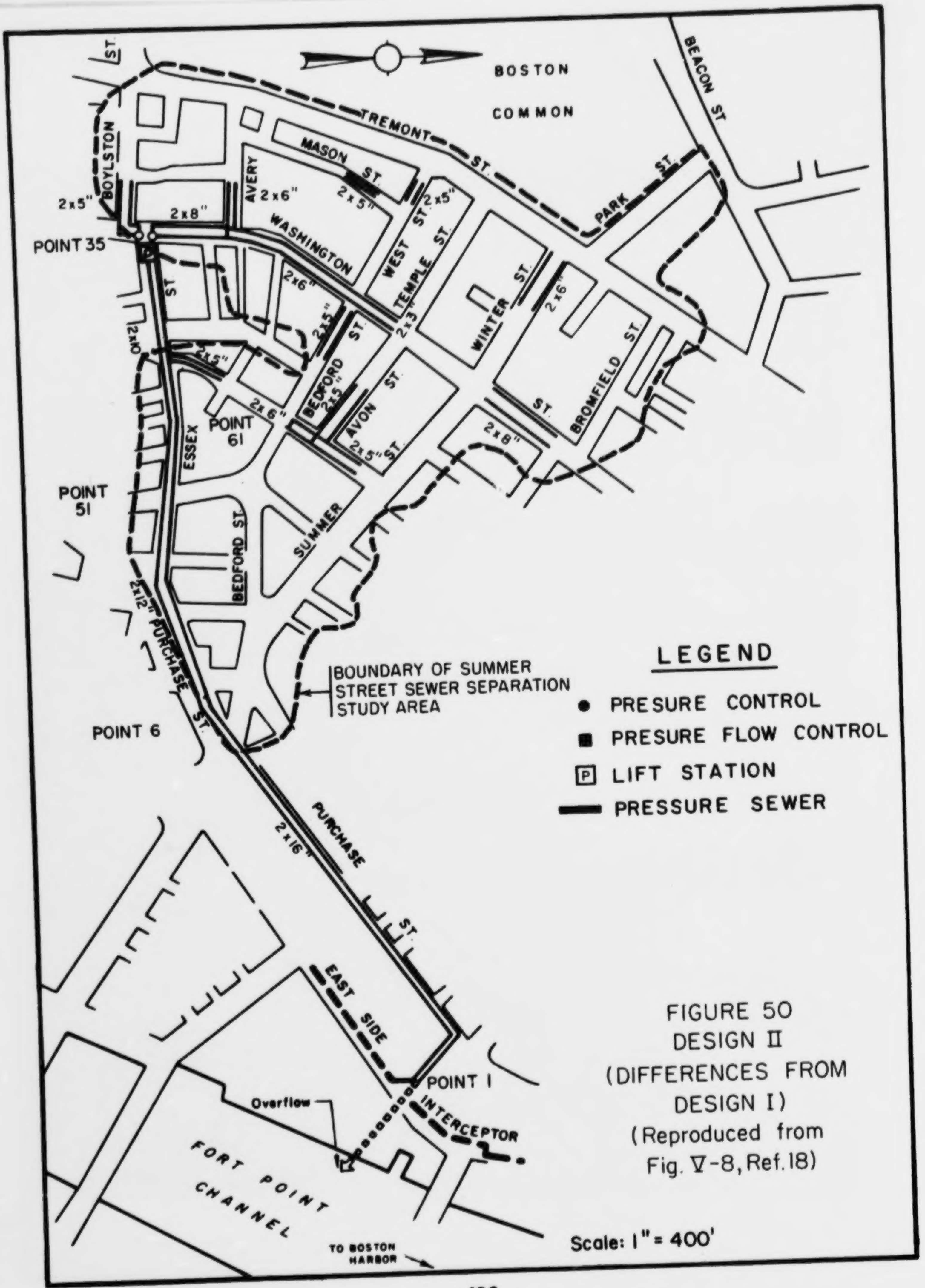
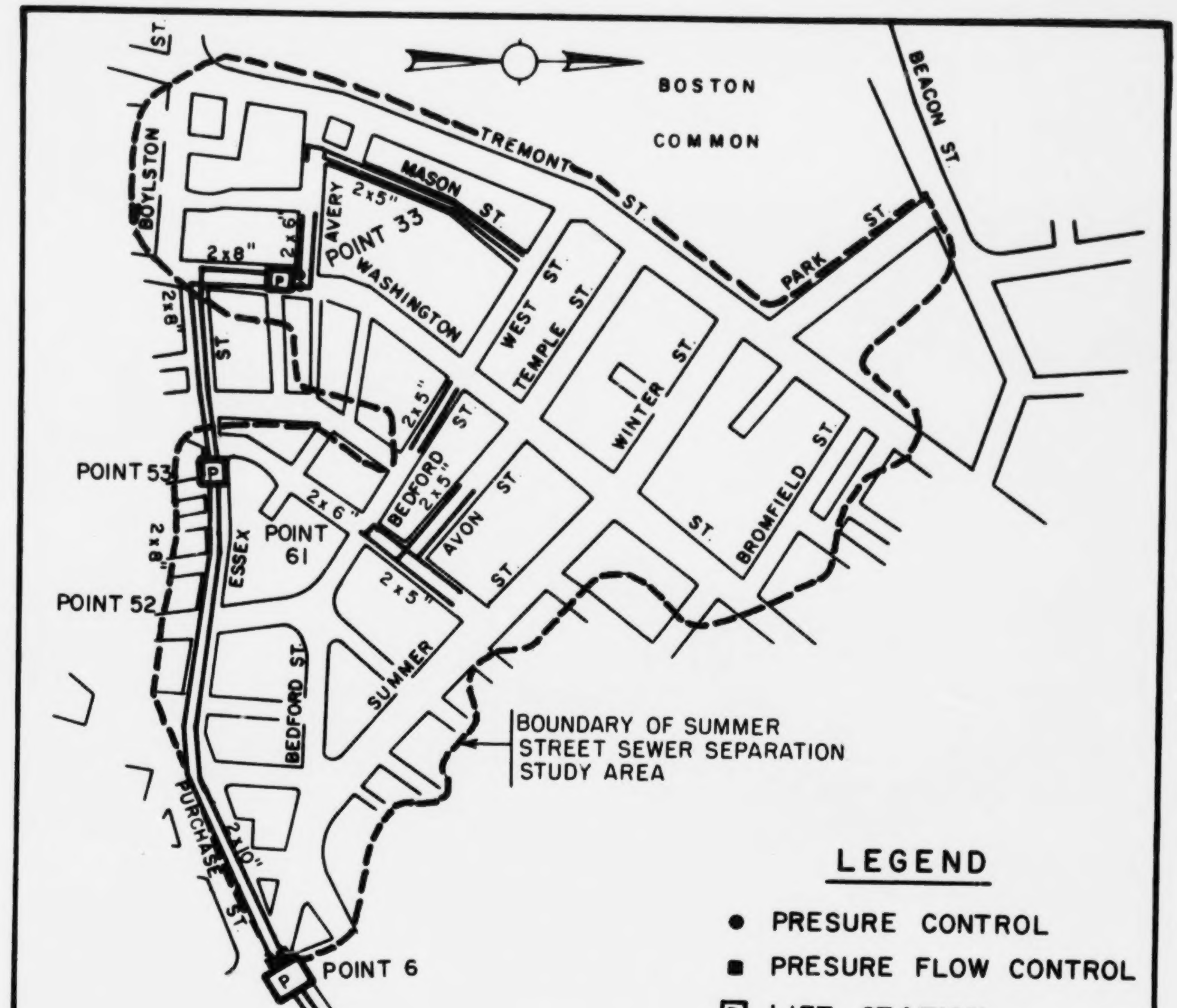


FIGURE 50
DESIGN II
(DIFFERENCES FROM
DESIGN I)
(Reproduced from
Fig. V-8, Ref. 18)



BOUNDARY OF SUMMER STREET SEWER SEPARATION STUDY AREA

FIGURE 51
DESIGN III
(DIFFERENCES FROM DESIGN I)
(Reproduced from Fig. V-10, Ref. 18)

TABLE 16

ANNUAL COST OF SEWER SEPARATION, PROSPECT AVENUE STUDY AREA, MILWAUKEE, WISCONSIN

HYPOTHETICAL APPLICATION OF ASCE COMBINED SEWER SEPARATION PROJECT
(Reproduced from Ref. 17)

	Project M-1			Project M-2		
		Annual Cost			Annual Cost	
PRESSURE SYSTEM	Construction Cost	Public Financing	Private Financing	Construction Cost	Public Financing	Private Financing
IN-HOUSE COST						
Total	$2,630,000			$2,630,000		
Minus Stor.-Grind.-Pump Cost	(519,000)			(519,000)		
Subtotal	$2,111,000	$150,000	$181,000	$2,111,000	$150,000	$181,000
Stor.-Grind.-Pump Cost	519,000	67,000	74,000		67,000	74,000
Power		1,700	1,700		1,700	1,700
Stor.-Grind.-Pump Maintenance		16,900	16,900		16,900	16,900
SUBTOTAL		$235,600	$273,600		$235,600	$273,600
AREA COLLECTION COST (All Public Financing)						
Constr. Cost Amortization	$ 595,000	42,000	42,000	$ 630,000	45,000	45,000
Op. & Main., Adm. & Gen. @ 1.25%		7,500	7,500		7,900	7,900
TOTAL COST	$3,225,000	$285,100	$323,100	$3,260,000	$288,500	$326,500

	Project M-Gr		
		Annual Cost	
GRAVITY SYSTEM	Construction Cost	Public Financing	Private Financing
IN-HOUSE COST	$1,114,000	$ 79,000	$ 95,000
AREA COLLECTION (All Public Financing)			
Constr. Cost Amortization	1,081,000	74,000	74,000
Op. & Main., Adm. & Gen. @ 0.5%		5,300	5,300
TOTAL COST	$2,195,000	$158,300	$174,800

In-house plumbing changes would probably be made by the property owner and their cost was assumed to be amortized at 7 per cent in 25 years. The cost of the storage-grinder-pump unit itself was assumed to be amortized over a 10-year period. For distribution of the total construction cost to the taxpayers through general obligation or revenue bonds, it was assumed that necessary funds could be borrowed at 5 per cent for 25 years for construction work and 5 per cent for 10 years for the storage-grinder-pump unit.

The cost of work done in the public right-of-way is normally financed by the municipality, and it can be assumed that the construction cost of an area collection system can be amortized at 5 per cent in 25 years.

In Table 16, costs related to operation for the alternative schemes are based on the following prices:

1. Power: $0.030/Kwh, paid by individual property owners.
2. Storage-grinder-pump Unit: Estimated as one maintenance call per year per unit, at $20/visit.
3. Routine Operation and Maintenance: Estimated at 1 per cent of the construction cost for pressure systems, and at 0.25% for gravity systems.
4. Administration and General: Estimated as 0.25% of the construction cost.

Estimated annual costs for a conventional gravity system are from 7.2 to 8.0% of the estimated construction cost for a gravity system, Table 17. In comparison, estimated annual costs for the two alternative pressure systems range from 13.0 to 14.9% of the estimated construction cost for a gravity system, Table 17.

Summary and Comparison of Estimated Costs, Three Study Areas

Table 18 summarizes the estimates of construction costs for the three studies. The engineering consultants estimated (1) construction costs for capital investment in round numbers, and (2) ratios of costs between pressure and gravity designs as follows:

	Pressure	Gravity	Ratio
San Francisco	$13,000,000	$8,800,000	1.5
Milwaukee	3,200,000	2,200,000	1.5
Boston	6,400,000	4,700,000	1.4

TABLE 17

COMPARISON OF ANNUAL COSTS FOR MILWAUKEE STUDY AREA

Project	Estimated Project Construction Cost (1)	Estimated Annual Cost (2)	Estimated Annual Cost As A Percentage: Relative to Construction Cost of Given Alternative** (3)	Estimated Annual Cost As A Percentage: Relative to Gravity System Construction Cost*** (4)
Gravity System				
M-Gr				
All public funds*	$2,195,000	$158,300	7.2	7.2
Public & private	2,195,000	174,800	8.0	8.0
Pressure Systems				
M-1				
All public funds*	3,225,000	285,100	8.8	13.0
Public & private	3,225,000	323,100	10.1	14.7
M-2				
All public funds*	3,260,000	285,500	8.7	13.0
Public & private	3,260,000	326,000	10.0	14.9

* Except cost of electric energy.
** Column (2) ÷ Column (1), in per cent.
*** Column (2) ÷ $2,195,000, in per cent.

TABLE 18

ESTIMATES OF CAPITAL COST

HYPOTHETICAL APPLICATION OF ASCE COMBINED SEWER SEPARATION PROJECT

	San Francisco, Cal.		Milwaukee, Wis.		Boston, Mass.	
Engineering News Record Construction Cost Index	1320		1200 (if mid-1968)		1250	
Capital Costs	Pressure (Alt. B)	Gravity	Pressure (M-1)	Gravity	Pressure (Des.I)	Gravity
Plumbing Separation and Connection to SGP Units	$4,416,000	--	--	--		
Connection as far as property lines	--	5,413,000	--	--		
Connection to laterals	--	--	1,214,000	1,140,000		
SGP-Units (or comminutor-pump equivalent)						
Alone	--	--	1,417,000	--		
And connection to laterals	5,304,358	--	--	--		
Connection, property lines to laterals	--	1,003,075	--	--		
Subtotals	9,720,000	6,416,075	2,631,000	1,140,000	4,000,000	2,000,000
Area collection systems	3,313,626	2,374,848	594,000	1,055,000	2,400,000	2,700,000
TOTALS	$13,033,984	8,790,923	3,225,000	2,195,000	6,400,000	4,700,000
Unit Costs						
Per gross acre	$40,350	27,220	20,600	14,000	128,000	94,000
Per connection	$ 4,700	3,170	3,830	2,610	32,000	23,500

It would appear, therefore, that including changes in building plumbing the separation of a combined sewer system by the method studied for the ASCE Project might cost about half again as much as separation by the conventional method of laying a second system of gravity conduits.

In terms of total costs for building plumbing changes and connections to street laterals shown in Table 18, neglecting street sewers:

	Pressure System, Including SGP Unit	Gravity	Ratio
San Francisco	$9,720,000	$6,420,000	1.5
Milwaukee	2,630,000	1,140,000	2.5
Boston	4,000,000	2,000,000	2.0

The ratios of cost are shown to vary from 2.5 to 1.5.

Evaluations and Conclusions of Engineering Consultants

Some principal evaluations and conclusions of the engineering consultants, extracted from various parts of their reports, are quoted as follows:

San Francisco Study Area (from Brown and Caldwell report, Ref. 16)

"Factors which would tend to lend an economic advantage to pressure systems are high density of existing development, complexity of existing substructures, and inadequate ground slope. The latter factor results in large diameter gravity sewers and a greater number of sewage pumping stations. It appears from the cost data developed in this report that a net capital cost advantage would accrue to the pressure sewerage scheme only if all of the above factors were favorable, in the extreme, to the pressurized system design. It is unlikely that such an area exists in San Francisco.

"Components of the pressure sewerage system which hold most promise for cost reduction are fittings, control appurtenances, and the grinder-pump assemblies. Fittings, manholes, and special appurtenances account for about 40 percent of the total cost of the pressure conduit network. Development of special fabricated fittings to perform the several functions of main-to-trunk connections, cleanouts, and pressure control might save as much as one-third of the cost of the piping appurtenances. Experience with freely discharging conduits may indicate that pressure control works are unnecessary. This modification would reduce total costs by a few percent. A reduction in the number of cleanouts and by-pass connections might be made if operating and maintenance experience with pressure sewer networks is found to be very favorable. The potential cost reduction in this case is limited to a few percent of total system cost. The estimated cost of the grinder-pump equipment modules represents about one-fourth of the total cost of the pressure sewerage system. If the advent of pressure sewer systems develops a mass market for grinder-pump equipment it seems likely that major cost reductions will be achieved.

"This study does not include any estimates of operating and maintenance expenses. Clearly, these costs would be greater for a pressure system in every instance. Relative importance of comparative operational costs and capital costs should be evaluated for some specific cases.

"Service reliability of a conventional gravity sewage collection system is excellent. Pressure system components would be designed with great care to enhance their reliability and serviceability. Nevertheless, it is certain that a pressurized system would suffer more outages and cause more resident inconvenience than a conventional gravity system.

"Disruption of normal street and property usage can be held to a minimum during construction of pressure pipeline systems. This is an advantage of the pressure sewer scheme which will obtain in all cases. In an area such as a downtown shopping district, this factor could be of considerable importance.

"In total, it appears that, for the San Francisco study area, the favorable features of a pressurized wastewater collection system cannot compensate for its economic disadvantages. The pressure system design is believed to hold little promise for wastewater and storm drainage separation in areas such as the one studied here."

"In sum, it is felt that the pressure system design for wastewater and storm drainage separation holds little promise in areas similar to the San Francisco study area."

Milwaukee Study Area (from Greeley and Hansen report, Ref. 17)

"Aside from cost considerations, in our opinion it would be unwise to embark upon major pressure system projects until experience with pilot installations has demonstrated that operation and maintenance difficulties are not of serious consequence. Although for the Milwaukee test area the pressure system is estimated to cost much more than the gravity system, it is possible that in other situations the cost relationship will be different."

"The cost of in-house plumbing changes would be only slightly higher for a pressure system. The collection system cost for the pressure system would be only about 9/16 that for a gravity system, but this is much more than offset by the added cost of providing and installing grinder-pump units. Even though pressure system components were developed to lesser unit cost levels as a consequence of market demand, it is likely that the costs for pressure systems would significantly exceed the costs for gravity systems.

"The pressure systems have, in addition to higher costs, the drawback of being dependent on electrical power for their operation. In addition, grinder-pump units in each house require that construction be done in each home, possibly damaging the basement as a dwelling unit.

"Engineering and construction of a pressure system can be accomplished. However, in view of the economic disadvantages and intangible problems such as public relations, it seems unlikely that a pressure system used for separation of combined sewage would be found advantageous in the Milwaukee test area."

Boston Study Area (from Camp, Dresser and McKee report, Ref. 18)

"All of the above costs are for construction (including engineering and contingencies) only. While the gravity separation system would have minimum annual maintenance cost, the pressure systems would require considerable operating and maintenance cost because the flows from each building would have to be pumped into the street force mains. Based on reports and data furnished by the ASCE Project, appreciable annual maintenance costs also would be required for pressure systems.

"The concept of hanging pressure force mains inside large existing combined sewers has been investigated. Estimates indicate that construction of pipes inside combined sewers would be more costly than the construction of a two-pipe system of comparable size located in the same streets. In addition, the capacity of the existing combined sewer would be considerably reduced, and maintenance difficulties of both the combined sewer and the hanging pipe system would be severe."

"While these estimated construction costs are preliminary only, it is our opinion that they are sufficient to show that there is no economic advantage in constructing pressure sewer systems over a conventional gravity system. In addition, the pressure sewer systems have the further disadvantage that they would have significant annual operation and maintenance costs. The annual operating costs have not been estimated, but it is evident that they would be major. Pumps and control equipment have an expected design life of about 20 years, whereas gravity connections should have a life of about 100 years. Therefore, there would be a recurring capital outlay to keep the pressure system in operation.

"An additional factor which must enter into any comparison of sewer systems is the likelihood of failure or improper operation. A gravity system properly designed is essentially free of the significant possibility of failure by its very nature. On the other hand, a pressure system with its numerous mechanical equipment and control features, is subject to regular though unpredictable failures. At any given time during the life of such a system (composed of pumping, grinding, pump control, pressure control and back-flow prevention equipment), jamming, clogging, power failure or equipment failure can be expected. The possible flooding damage and inconvenience which may occur during a period of repairs may also involve considerable additional costs.

"It is evident that to keep a pressure system in 100 per cent satisfactory operation is almost impossible. A frequent maintenance schedule for the many building units and main pumping and pressure control equipment is required.

"In our opinion, the problems of operation and maintenance of a pressure system together with higher estimated construction costs indicate that such a system is not a feasible solution to the problem of separation in large cities."

SECTION X

BROADER ASPECTS OF PLUMBING SEPARATION*

Introduction

Separation of private building plumbing systems is an important element in the separation of combined systems of sewerage for both conventional and ASCE Project schemes. It represents a substantial portion of the total construction costs in either case. Cost estimates for street sewerage are made reliable by the accumulated and accessible information on such undertakings. By contrast, there are few public records on the nature and cost of plumbing modifications on private property. Moreover, costs fluctuate widely because of the particularized requirements of individual buildings.

Separation of private plumbing systems has been reviewed in Section IX for the study areas of San Francisco, Milwaukee, and Boston, and cost estimates by the three consulting engineering firms connected with these studies are included in Table 15. In order to augment and categorize costs for these three cases a survey was made of seven other large cities (Ref. 13): Cleveland, St. Louis, Detroit, New York City, Washington, Chicago and Philadelphia. Wanted information was supplied by city officials and local plumbing contractors, and additional information was obtained from Charles A. Maguire and Associates for a 430-acre urban-renewal area in Boston and from the findings of the American Public Works Association Research Foundation in its recent study of combined sewer systems (Ref. 27).

Details for typical piping arrangements and auxiliary data are given in the appendix of Reference 13.

Summary

A summary of information on the separation of plumbing systems in the ten cities follows:

(1) Differences in the nature and scale of the plumbing-system work required for the conventional and ASCE Project schemes can be summarized as follows for most private residences:

a. The ASCE Project scheme requires the installation of a storage-grinder-pump unit in the building drain downstream from existing fixture connections.

---

* Ref. 13.

b. Instead of requiring a new gravity building sewer leading to a public gravity sewer, the ASCE Project scheme calls for the installation of pressure tubing between the storage-grinder-pump unit and a proposed public pressure sewer. In most ASCE Project scheme applications, the associated difficulties and costs for typical plumbing arrangements would, at worst, not exceed those for conventional building separation; in some cases they would be simpler and/or less expensive. However, the ASCE Project scheme is more likely to entail the correction of plumbing inside buildings, with attendant difficulties and costs.

c. If the existing building system is not completely separate (i.e., if illegal balcony drains, deep window-wells, foundation drains, and the like are connected to the system) the additional hydraulic load placed on the pressure piping may exceed the normal design capacity of the storage-grinder-pump units for sanitary flows.

(2) In the five cities for which data were available:

a. 50% to 60% of the total land area is occupied; streets, vacant properties, and open areas such as parks and cemeteries being excluded.

b. 50% to 70% of the occupied land area is residential.

c. 80% to 90% of the individual properties are residential.

d. Only a small proportion of the residential properties house more than four or five families.

(3) Row housing is common in Philadelphia, Boston, Washington, and some parts of New York City. It is uncommon in the other seven cities.

(4) In Washington, St. Louis and Detroit, most residential sewers are located in alleys at the back of the houses. The other seven cities are provided mainly with street sewers.

(5) The plumbing codes of all ten cities require storm drainage from buildings to be piped to existing storm or combined sewers. In smaller communities such connections are normally prohibited.

(6) Washington and Philadelphia require rear yard drains on each property, and Chicago requires catchbasins for kitchen-sink wastes.

(7) It is expected that the plumbing systems in the ten cities can be separated before they reach the building drain. Balcony drains connected to such systems in violation of the plumbing code are possible exceptions.

(8) Separation of plumbing systems in residential buildings, exclusive of those in Detroit and about half those in Cleveland, involves disconnection of existing roof leaders at the front and rear of each house. About half the houses in Cleveland have separate plumbing systems. In Detroit most buildings are provided with separate drains as far as their junction at the building sewer in the vicinity of the foundation footing.

(9) Only in Detroit would separation generally not involve reconstructing the existing storm drainage system. However, work to be done would usually extend into the buildings only in row houses or non-residential buildings.

(10) Foundation drains are uncommon in most of the ten cities. In Chicago they are used only for larger houses. In Detroit and about half the houses in Cleveland, the foundation drains are connected to storm drains and intercept roof water. Other Cleveland houses could install a shallow storm drain to intercept roof water alone or a deep drain to accept both roof water and foundation drainage.

(11) Most large buildings have interior downspouts.

(12) Records of plumbing layouts and modifications are not available for many older buildings.

(13) In many downtown buildings, basement floors lie below sewer level and drains are suspended from basement walls or ceilings. Therefore separation could be effected without excavating below basement floors.

(14) In some of the ten cities, the drainage systems of significant numbers of large buildings had been separated at the time of construction up to the building front or the street sewer, either to reduce flooding or costs.

(15) In four of the ten cities, separation of plumbing systems in new buildings is required by regulations introduced during the past ten years. This has resulted in a significant number of structures with separate systems in downtown areas.

(16) Most of the following alternatives to piped roof-water connections have been used where storm sewers were not available:

a. Installing splash blocks or providing piped connections to pervious areas or streams on private properties, as in Washington, D.C. Discharging roof water directly onto the ground in designated areas now being considered in Chicago and already allowed in some Detroit suburbs.

b. Regrading surfaces to divert storm water from deep window wells, for instance, where area drainage can not be economically separated from the sanitary system.

c. Roofing or enclosing small areas originally drained to the system when the drains can not be economically disconnected from the sanitary system.

d. Installing curb drains to conduct roof or surface water under a sidewalk to a street gutter.

e. Diverting roof water to more convenient collection points. Introduction of horizontal drains into the attics of large buildings has been suggested as a way of bringing roof water to the front of buildings. New roof gutters have been provided here and there in Washington.

(17) In Washington it was found that separation of the drainage systems of some buildings was impractical or uneconomical.

Building owners cannot be depended upon to separate existing plumbing systems fully. Financing extensive plumbing changes, especially in older buildings of marginal economical value, may be difficult and may impose a hardship on some owners. Compliance, even by financially capable owners, might be difficult to enforce unless strict ordinances were enacted. Teams of inspectors would be required to ensure full compliance with the ordinances. It would seem better for municipalities to provide crews to do the work in all buildings. However, making necessary political, financial, and legal arrangements to do this might be intricate and controversial. Many buildings would have to be renovated extensively to permit separation.

Table 19 gives the estimated costs of plumbing separation on private property based on the data obtained for the ten cities; 1968 prices are used. They include normal allowances for contractors' overhead and profit and contingencies.

a. For the San Francisco study area allowances were made for disruption of normal property use. They ranged from $100 per structure for one- and two-family residential buildings to $400 for commercial, industrial, and similar buildings. The mean value was $2,100 per acre.

b. At Washington, costs of public relations and planning for separation varied from $140 to $250 per residential building or from $260 to $1,950 per acre.

c. Cleveland estimates provided for a cost escalation of 14 per cent, or about $1,500 to $2,000 per acre, for anticipated cost increases over a seven-year construction period.

TABLE 19

SUMMARY OF INFORMATION ON COSTS OF BUILDING PLUMBING SEPARATION (1968 LOCAL COST LEVELS; INCLUDES ALLOWANCES FOR CONTRACTORS' OVERHEAD AND PROFIT)

(Table J-1 of Ref. 13)

City	Row Houses		Detached Houses			Industrial		Office Buildings, Large Apts., etc.		Housing Project	
	$ per building	$/occupied acre	$ per building	$/occupied acre	$ per gross acre	$ per building	$/occupied acre	$ per building	$/occupied acre	$ per building	$/occupied acre
Boston											
-Urban Renewal Area	700	15,000									
-Study Area(a)								10,000(d)	43,600(g)		
Cleveland			2,024	12,900 to 13,800(b)		4,300	9,000(b)				
New York								13,000	25,000	23,600	1,510
Washington, D.C.	750		1,750 to 3,230(c)		9,000 to 3,280			6,189(h)			
Chicago			1,030	11,300	6,600						
St. Louis			5,000	47,000	26,000						
Detroit			1,650	15,900	9,300						
Philadelphia			600	17,300	9,700						
San Francisco -Study Area(a)			1,720(d)	20,700(e)				2,120(d)			
Milwaukee -Study Area(a)			1,650(f)	12,800(f)				2,600(i) 2,100(j)	7,500 11,300		

(a) Refs. 16, 17 and 18.
(b) Area includes street areas.
(c) Estate-type houses on large properties.
(d) Cost includes work to property line only.
(e) Residential-commercial area: residential, 2,434 bldgs.; commercial and other, 339 bldgs.
(f) Based on 606 residences, 94 stores and stores with houses over.
(g) Based on study of one 10,000 sq. ft. commercial bldg.
(h) Mean for 41 buildings.
(i) Apartment buildings.
(j) Office and institutional buildings.

d. Cost of repair or renovation of finished basement areas was not allowed for.

e. Recorded per acre costs for Washington assumed that all buildings are provided with combined systems. No allowance was made for buildings that might be partially or completely separated.

The costs in Table 19 expressed in terms of cost per occupied acre are probably most useful, because they are based in so far as possible on the areas occupied by buildings in which plumbing would be separated. Vacant land, parks, cemeteries, streets and alleys were excluded.

Although some of the costs in Table 19 vary widely, it is possible to say that the estimated cost per occupied acre for residential housing (with the exception of data from St. Louis) lies between $11,000 and $17,000 per acre. The only available estimate for industrial buildings of $9,000 per acre is based on a unit area including streets. If the street area is assumed to be 25 per cent the cost would be $12,000 per occupied acre. Data for large buildings range from $7,500 to $43,600 per occupied acre. The cost for a mixed residential-commercial area in San Francisco was placed at $20,700 per occupied acre.

Table 19 supports the American Public Works Association's estimate for nation-wide building separation of $18.4 billion (Ref. 27), if that cost is not taken to include supplementary costs such as disruption of use. Because the estimated total area served by combined sewers in the United States is 3,029,000 acres, the approximate cost of building separation is about $6,100 per gross acre. Assuming that 55% of the total acreage is occupied, the unit cost becomes $11,100 per occupied acre. This value lies at the low end of the range shown in Table 19, but it appears to become an average figure if small cities and suburban areas with relatively few buildings per acre are included. The APWA estimate is based on less information than that provided in Table 19, but the values used are reasonably consistent with those in the table.

Taken as a whole, the data summarized here are considered to offer a suitable basis for valid generalizations about costs of separation of building plumbing systems on private property. Where reliable estimates of the cost of building separation are required, on-site studies should be made of a sufficient number of buildings to identify existing problems and costs. Such studies would constitute a necessary preliminary step in a full-scale field demonstration of the ASCE Project scheme.

SECTION XI

NON-TECHNICAL CONSIDERATIONS RELATED TO PRESSURE SEWER SYSTEMS*

Introduction

One of the objectives of the ASCE Project study was to evaluate the importance of related non-technical matters such as home-owner acceptability and ownership and maintenance of system components. It was assumed that proof of the physical and economic feasibility of the ASCE Project method of combined sewer separation would otherwise resolve questions normally related to the construction of sewer systems such as public financing, establishment of an administrative and operational organization, and necessary legal and legislative decisions. Accordingly the problems uniquely related to the project are of primary interest in this section. Among them, in particular, are the need to separate building plumbing, to install storage-grinder-pump (SGP) units in private as well as public properties and to convince property owners that these changes will be made to their profit in spite of some inconvenience and possible out of pocket expenses to themselves. This might not be an easy task.

Convincing the public and their elected representatives of the advantages of sewer separation by a scheme of the ASCE Project type, other non-technical considerations include study and determination of: (1) who should purchase, install, replace and hold title to SGP units and tubing inserted in building drains and sewers and who should pay for the amortization of the capital cost and interest on investment; (2) whether the community as a whole or the individual property-owner should pay for operation, including cost of electric energy (a minor annual cost), and routine servicing, emergency repairs, and parts replacement; (3) what agency should actually perform the maintenance, repairs, and periodic inspections; (4) where the responsibility should lie for damages from malfunction of an SGP unit, or stoppage in a pressure service connection; and (5) who or what agency should pay the costs for required plumbing changes within private properties.

Specific answers to such questions of public policy are hard to find. However, there are some records of what has been done before in the development of sewer systems, and parallels can be drawn also from policies adopted by public utilities. These are examined in the next two parts of this section. Additionally, the essence is presented of interviews conducted by ASCE Project staff at Louisville and Radcliff, Ky., and with three consulting engineering firms that have been interested in sewerage schemes involving sewage pumping equipment on private property. Interviews are reported in Ref. 12, and comments on how to obtain the cooperation of building owners are given in Ref. 13.

---

* Ref. 12.

Public Acceptance and Financial Support

Existing building plumbing must be restructured in conventional separation as well as in the ASCE Project scheme. However, the addition of the SGP equipment within the building or adjacent to it is a unique requirement of the ASCE scheme alone. The associated benefits and disadvantages of the ASCE Project scheme to the individual householder are discussed in Section XII.

Most important is the cooperation and consent of building owners, individually and as voters. Engineers suggest that opinion and, to a limited extent also, practice would be in favor of installing and maintaining the SGP equipment and tubing as a public purpose.

To be considered, too, are: the direct burden of temporary disruption of normal activity while piping is being changed and equipment installed; the loss of space occupied by the SGP unit; and such inconvenience and minor nuisance as the unit may create.

In general and as well as in situations where one drainage district is served by gravity sewers and another by pressure sewers it would appear desirable to equalize the financial burden of sewerage: (1) by reimbursement of the cost of minimum plumbing changes; (2) by furnishing, installing, and maintaining the SGP unit as a public responsibility of the community; and (3) by providing a fast and responsive repair service as well as adequate maintenance and inspection. Damage by flooding caused by unit malfunction should be paid for from public funds or by insurance with premiums paid by the community.

Common precedents for outside ownership and maintenance of service and metering equipment on private property are set by telephone services (equipment), water companies and departments (meters), gas and electric power companies (meters) and, in some parts of the country, heating appliances. Where sewer service charges are imposed, rate differentials could offset the cost of electric energy for operating the SGP unit. Even though it would be a minor cost, public acceptance might be encouraged by taking it into account.

Direct Precedents

A precedent for also separating combined sewers on private property at public expense has been set in Washington, D.C. There it was reasoned that: "Since the separation of plumbing on any single premise is of no specific benefit to the owner, but rather is an incremental part of a larger and general public benefit, the municipality is standing the entire cost of such piping changes. . . . It is recognized that the combined plumbing systems were installed according to city codes and that property owners are not obliged to change them." An extensive public relations program has thus far induced all but 4% of the building owners to agree to the alteration of their systems. (Ref. 39).

Well known is the fact that in 1953 the village of Shorewood Hills, Wis., introduced community-wide installation of garbage grinders that were purchased, installed, and owned and maintained by the community. All property owners accepted their grinders, and it was agreed that because the grinders were a clean and convenient means of disposing of garbage they eliminated the nuisance associated with the storage and hauling of garbage through the streets of the community, a practice that could, therefore, be prohibited by ordinance. (Ref. 40).

Sampling Public Attitudes

To obtain the response of individuals acquainted with the behavior of pumping equipment on private property, householders and the superintendent of the sewer system in Radcliff, Ky., and representatives of three consulting-engineering firms were interviewed (Ref. 12).

At Radcliff (Refs. 12 and 41), small portions of an otherwise gravity system are served by pressure sewers through which domestic sewage is lifted to the gravity mains by pneumatic ejectors. Almost all the pumping units are in pits outside single-family houses. The ejectors were purchased and installed under public contract, as appurtenances to the community system, and they are maintained by a public agency. Property owners pay about 10 cents a month for the electric power consumed. Construction costs were financed publicly, partly with Federal aid. A connection charge and a sewer-use charge pay for operating the units and amortizing the system. Costs of pressure as well as gravity connections to the premises served were borne by the property owners. Most of the ejectors have required frequent repair and maintenance, generally in response to telephone requests for assistance to a repairman on call.

Twenty-five households were asked about the pressure facilities, most of which were installed in 1964. Responses with regard to pumping units are summarized in Table 20. Noise and vibration led the list of complaints about the pneumatic ejectors. Eight inside and 3 outside installations bothered the householders greatly. Odors, frequency of interruption, and limitation of fixture use were other grounds for complaint. Possible flooding was a source of worry in 15 responses. A majority of the people questioned were not pleased with the ejectors. The poor performance of the pumping system employed at Radcliff may have depreciated the value of the properties served.

TABLE 20

ATTITUDES OF OCCUPANTS OF TWENTY-FIVE BUILDINGS TO EXPERIENCE WITH PUMPING UNITS, RADCLIFF, KENTUCKY

(Reproduced from Table 1 of Ref. 12).

(a) Number responding to question: "To what extent do each of the following bother you?"

	Not at all		Slightly		Somewhat		Greatly		Not applicable in view of other answers
	Units Inside	Units Outside	Units Inside	Units Outside	Units Inside	Units Outside	Units Inside	Units Outside	
Noise	-	12	-	1	-	1	8	3	-
Odor	3	12	2	1	-	2	3	2	-
Expense	6	11	1	3	-	-	1	3	-
Appearance	6	8	-	4	1	1	1	4	-
Loss of Space	6	10	-	4	1	-	1	3	-
Limitations on Fixture Use	6	11	-	2	-	2	2	2	-
Interruptions of Service	1	5	2	3	2	2	3	4	3
Source of Worry	1	5	-	4	3	4	4	4	-

(b) Relative preference for pumping unit versus previous system

	Previous System Preferred		Pumping Unit Preferred		No Preference
Previous System	Slightly	Definitely	Slightly	Definitely	
Public System	2	10	-	1	-
Septic Tank	-	6	2	2	2

(c) Response to question: "In view of your experience with the pumping unit, would you make the same choice again?"

(i) Converted from septic tank or constructed new house, and no choice was available regarding adoption of unit - 14

(ii) Bought or rented house: would make same choice - 2
would not make same choice - 9

At Lousville, 5 householders, all General Electric Co. employees, agreed to the temporary installation of sewage sampling units in their yards. Equipment and operation were paid for by the company. The stations consisted of field-assembled grinders and pumps set in small vaults at or just below ground level outside the houses. Although none of the householders questioned were particularly bothered by the units, 3 did report noticing slight noises at night when bedroom windows were open and one said he had occasionally noted a brief odor.

Representatives of Sieco, Inc., Consulting Engineers, Columbus, Ind., have become interested in the possibilities of rural pressurized sewer systems employing a storage-grinder-pump unit and plastic discharge tubing. In their opinion, pumping units for individual buildings provided, installed, and serviced by the community would have greater acceptance than private installations and would be better serviced. Moreover, there would be better acceptance of such installations for new rather than existing systems where pressure systems offered a practicable and economical solution of a sewerage problem.

The cost of gravity sanitary sewers is a function of trenching depth which, in turn, depends on the elevation of the lowest plumbing fixture in the building served. A representative of Williams and Works, Consulting Engineers of Grand Rapids, Mich., has long considered the merits of a system in which domestic sewage would be lifted by storage-grinder-pump installations in individual basements into conventional gravity sewers laid at less than normal depth. Duplicate units might be installed to increase reliability of operation.

A representative of Prince William Engineering Company, Woodbridge, Va., stated that his firm believed that pumping units for new housing developments should be purchased and installed by the property owner and that contracts for maintenance and repair should be made with commercial agencies. Moreover, that pumping unit installations should generally be located outside the dwelling.

SECTION XII

BENEFITS AND DISADVANTAGES OF THE ASCE PROJECT SCHEME

In this study and report, the advantages of combined sewer separation by the ASCE Project scheme have been compared mainly with conventional sewer separation by construction of a second system of conduits for sanitary sewage or for storm drainage. Other methods of accomplishing abatement of pollution of receiving waters from overflows from combined sewers have also been pointed out, and their relative advantages have been compared with conventional separation (Section III).

Benefits to householders would chiefly be a generally improved environment through the regional abatement of pollution of receiving bodies of water. On the other hand, household storage-grinder-pump units may be a direct cost to the houseowner who may furthermore face a loss of space in his basement or yard and a risk of flooding in the event of the malfunctioning of the pertinent equipment (grinders, pumps, and valves).

Advantages and disadvantages of the ASCE Project scheme are summarized in Table 21. Major advantages over conventional separation are: (1) the elimination of all seepage waters from all pressurized reaches, and a consequent reduction in the hydraulic loads placed on treatment plants; and (2) reduced interference with commerce and traffic at construction sites. Most important, however, is the fact that pressurized systems are a viable alternative to gravity systems and that necessary technical information has been assembled by the ASCE Project to identify the relative merits of pressure versus gravity systems. There will be sectors and service districts of existing combined systems and of new separate systems where the pressure sewer system will prove to be the superior alternative. However, it is expected that there will be few major cities where pressurized sanitary sewerage will be the exclusive superior alternative.

Adjunct Applications

Adjunct applications of pressure-sewer concepts developed under the auspices of the ASCE Project are important and may be of benefit in many locations. The core equipment consisting of a household storage-grinder-pump unit, pressure tubing and conduits, and control valves may be suitable where conditions are unfavorable for the economical installation of gravity systems. Examples are: (1) an area of ridges and valleys through which a main sewer can not be extended within the lowest valley for political or other reasons; (2) steeply sloping shores of lakes where

TABLE 21

EVALUATION OF ASCE COMBINED SEWER SEPARATION PROJECT SCHEME

Factors for Consideration	Benefits and Advantages	Disadvantages
Planning and design:	An alternative to gravity systems, offering an additional degree of freedom in design.	
Effect on quality of receiving water:	Improvement by eliminating sanitary sewage.	
Effect on groundwater infiltration flows on capacity of sewage treatment plants:	Eliminate, reduce plant hydraulic load.	
Effect on hydraulic capacity of combined sewer converted to a separate storm drain if pressure conduit is suspended in sewer:		Reduce as much as 40%, depending on location and type of hanger system.
Effect on capacity of building drain and sewer if tubing is inserted in them:		Reduced capacity and contribution to stoppages.
Construction costs, ratio to cost of conventional sewer separation:		As much as 1.5,(a) depending on specific situations.
Construction activities:	Could minimize interference with commerce and traffic.	
Annual cost, ratio to cost for conventional separation:		As much as about 1.8,(b) depending on specific situations.
Anticipated public response to introduction of untried system, disrupting households for installation:		General public would need to be persuaded of the value to abate water pollution.

(Continued)

TABLE 21 (Continued)

Factors for Consideration	Benefits and Advantages	Disadvantages
Anticipated homeowner response:		Possible concern for flooding in event of a malfunction, and for payment for electrical energy.
Availability of Equipment -		
Household storage-grinder-pump unit[c]:	Prototype unit developed.	Untested in field service.
Comminutor and pump:	Commercially available.	
Tubing and conduit:	Commercially available.	
Control valves:	Commercially available.	
Operation of System -		
Routine inspection:		Required.
Repair and maintenance:		Difficult in some situations.
Valves for control:		Adjustment delicate and complex.
Reliability -		
Household storage-grinder-pump unit:		Untested, and subject to shutdown with electric power failure.
Tubing and conduit:		Occasional stoppages to be expected.
Subject to tampering:		Possible.

(a): Data from estimates for three studies, Refs. 16, 17 and 18 (see Section IX).

(b): Estimated for Milwaukee study area, Ref. 17 (see Section IX).

(c): Including backflow prevention valve.

individual or small groups of houses and cottages then can pump their wastewaters either to a pressure sewer at or near the shore line or to a higher-lying gravity sewer; (3) fixtures in basements or subbasements from which sewage must be lifted to the level of the street sewer; (4) introduction of pressurized sewers into utility conduits in common pipe tunnels or utility corridors for which gravity sewers cannot normally be employed; and (5) the isolation, comminution and selective water transport of essentially all readily decomposable organic waste substances from households and industries to existing, enlarged, or new waste treatment works (see Section XIII).

Hydraulic characteristics of pressure systems are explained at length in Refs. 6, 11, 16, 17 and 18.

SECTION XIII

APPLICATION OF ASCE PRESSURIZED SEWERAGE SCHEME TO DISPOSAL OF SOLID WASTES FROM HOUSEHOLDS AND INDUSTRY*

Introduction

The efficient and economical transportation, treatment, and disposal of solid wastes from households, industry and from the community at large without unwanted pollution of the urban environment has been recognized as a major need of our present and future cities and towns. Because it seemed that the pressure pipeline scheme for the separation of combined sewers might be expanded to this use, the possibilities of applying it also to the selective water transport of a wider range of household and industrial solids were given some study (Ref. 10).

As is well known, sewage collection and disposal systems have already been pressed into service to include ground garbage as well as normal sewage solids, and the question is whether pressurized systems can be employed effectively also for the transport of a wider variety of solid wastes. To be noted is that research on or development of suitable methods as such did not lie within the scope of the ASCE Project and that what is said in this section is only ancillary to the central project itself.

Available information on the collection and disposal of solid wastes by water carriage systems including the use of proprietary systems under study (as of 1968) is summarized in Reference 10. Alternative methods of collection and disposal are under intensive study in projects sponsored by the Federal Solid Wastes Program of the Environmental Control Administration within the Department of Health, Education and Welfare, under provisions of the Solid Waste Disposal Act of 1965.

Solid Wastes to Be Considered

Solid wastes comprised in the term municipal refuse are classified as garbage, rubbish, ashes, street sweepings, dead animals, abandoned automobiles, solid industrial wastes, demolition materials, sewage solids, and hazardous and special wastes. Garbage and rubbish are the most common components and are considered as such for discharge with sewage in the present section.

---

* Ref. 10.

For comparison with sewage of normal strength, Table 22 lists the loads that garbage and rubbish would add to sewage collection systems in general.

TABLE 22

TYPICAL QUANTITIES OF COMMUNITY REFUSE AND OF SEWAGE SOLIDS
(Ref. 10)

Type of Refuse	Gross weight (lbs/capita/day)	Dry weight (lbs/capita/day)	Concentration in sewage flow of 80 gcpd (mg/liter)
Municipal Refuse (20% moisture), total solids:	4 to 8	3.2 to 6.4	4800 to 9600
Residential Refuse (20% moisture), total solids:	2.0	1.6	2400
Residential Garbage (72% moisture), total solids:	0.5	0.14	214
Municipal Sewage,			
Total solids:	-	0.55	825
Suspended solids:	-	0.2	295
Biochemical oxygen demand (BOD):	-	0.12	180

Carrying Capacity of Sewers and Loads of Refuse Solids to Be Transported

The primary function of sanitary sewers, and combined sewers during dry weather, is to transport the solid matter in the sewage. So-called "minimum self-cleaning velocities" have been suggested for normal and some abnormal sewage solids, but, except for ground garbage, there has been little study of velocities needed to transport the heavier elements in other ground or pulped refuse.

Ground refuse from which glass and metals have been removed has been transported successfully in large-sized pipe lines for many miles. Ground solid wastes up to 1-in. in particle size have been transported in pressure pipe lines at concentrations up to 12% (Ref. 45). For concentrations up to 4%, observed head losses have not perceptibly exceeded those for water alone. At concentrations as low as 2%, solid waste slurries formed a colloidal matrix that tended to hold heavier materials in suspension, and minimum velocities required to sustain such suspensions have been found to be lower than those for lower concentrations of component solids dispersed in the transporting water.

Although mean flow velocities vary directly with rates of flow in pressure pipe lines and pipe sizes must be large enough to accommodate peak flows within reasonable hydraulic gradients, it is generally possible to maintain velocities that will transport some types of community waste solids during at least part of each day of the year. Pressure sewer laterals and mains could be sized to insure the occurrence of self-cleansing velocities with sufficient frequency to remove deposited solids before clogging or other objectionable conditions are created. Thus, the introduction into suitably-dimensioned pressure pipes of suitably well-ground solid wastes should be feasible although deposits might on occasion be somewhat greater in quantity.

The dimensions of sewage solids successfully transported in pressurized pipes are measures of the allowable sizes also of other waste matters that can flow through pipe and valve passages of pressurized sewer systems. Still to be considered, however, is the development of economical grinding and pumping devices for water-borne wastes other than sewage and garbage solids and, in addition, the determination of how much water is needed to create effective suspension of ground particles of different kinds. Clean water might be added if necessary, as in the use of garbage grinders, or specific solid wastes might be discharged into the system only when adequate volumes of water have accumulated in the storage-grinder-pump unit.

Separation and Grinding of Solid Wastes

As has been true for domestic garbage grinders now on the market, there are some solid wastes that are not suitable for grinding by the moderate-duty equipment so far developed for use in household and related building installations (Sections V and VI). Some large and hard-to-grind solid wastes would have to be disposed of in other ways. Some of them might be transported separately and in a dry state to central grinding stations capable of preparing them for transport through larger-sized downstream pressure sewers. The remainder might be collected and disposed of separately as is now the practice with bulky wastes. Common examples of such wastes are discarded major appliances, bed springs and automobile tires. However, the sorting and separate disposal of some of the solid waste components would presumably work against the acceptance of grinding units for processing waste solids in advance of their discharge of such solids either to pressure or gravity sewers.

Discharge to sewers of solid wastes not presently admissible to them would probably call for heavier duty equipment. This equipment might nevertheless be subjected to more frequent breakage than conventional sewage comminutors and the household sewage grinders developed in connection with the ASCE Project.

To reduce solid waste materials, such as bundled paper, rags, towels, corrugated boxes, tin cans, and bottles to acceptable size in advance of available household grinders, auxiliary "pulping" devices might have to be provided. Although these can presumably be developed, the economy of small-scale installations and their public acceptance are uncertain.

Treatment of Combined Solid Wastes

Sewage-carried solid wastes can be treated and disposed of by enlarging treatment and disposal units and mechanizing grit-handling, screening, sludge collection and sludge disposal. After grit removal, most of the ground solids would settle with the primary tank sludge. Available information suggests that the per capita sludge production might be increased 13 to 25 times, and that digester capacity might have to be enlarged even more than this because refuse solids have been shown to digest less readily than normal sewage solids. Gas production per pound of volatile solids added would presumably be reduced and the removal of accumulating solids would be more cumbersome. The organic loading of secondary treatment units is expected to be about two-thirds greater, whereas the organic constituents of ground garbage are known to respond well to normal sewage treatment processes. However, much remains to be learned about the response of other solid waste constituents. Processes designed for the treatment of normal sewage may have to be modified and new processes may have to be introduced to care for such solids.

Costs and Benefits of Collecting and Treating Solid Wastes with Sewage

Water carriage of a significant portion of community refuse and its effective disposal with sewage could add to the amenity and economy of community living. Potential net benefits and costs to the community should take into account the construction and operation of all of the structures required.

Figure 52 is a simplified schematic diagram of possible community systems for the disposal of municipal refuse with sewage. It illustrates ways in which solid wastes might be diverted to sewer systems from conventional disposal systems or from alternatives to conventional systems.

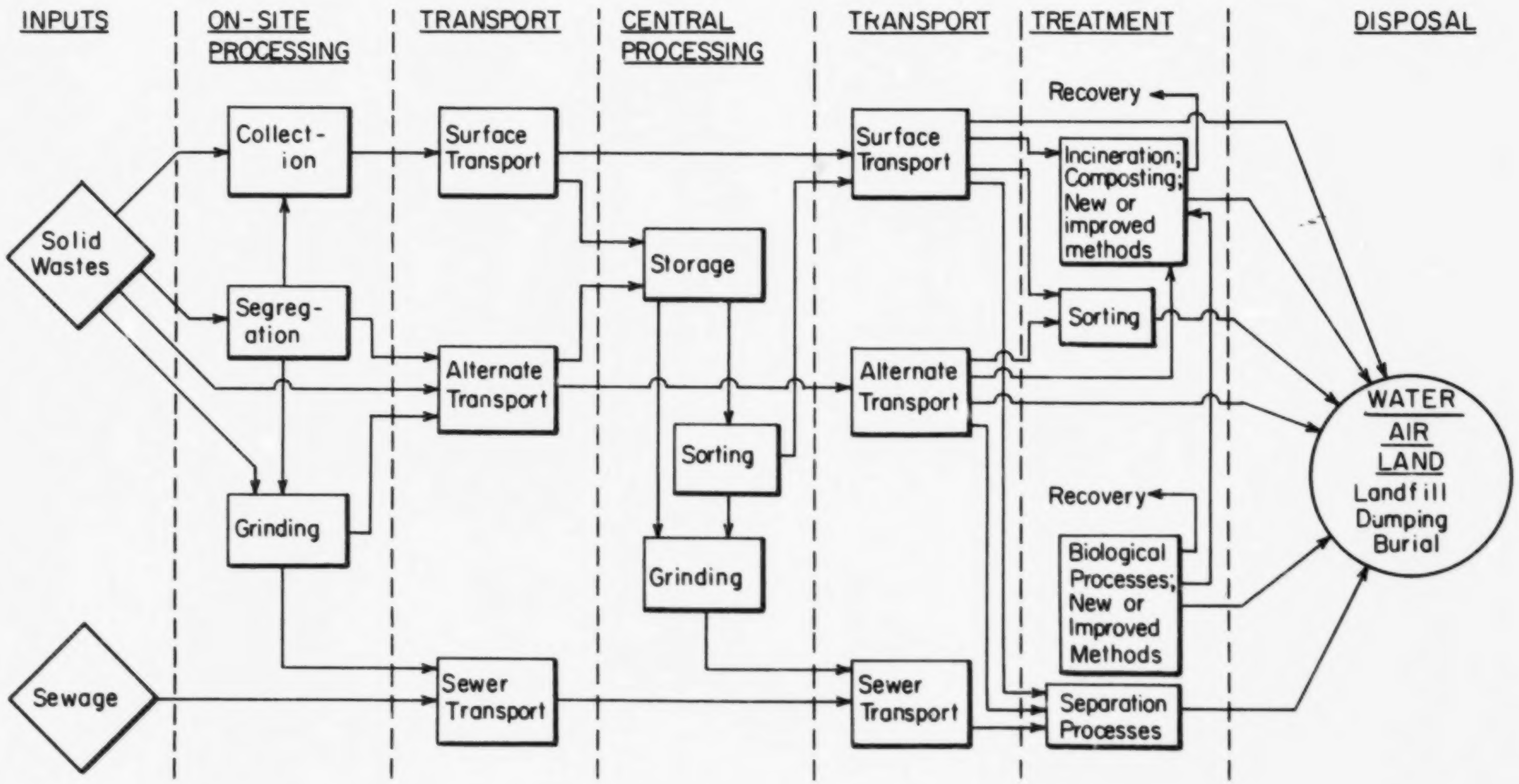


FIGURE 52
SCHEMATIC DIAGRAM OF SYSTEMS FOR DISPOSAL OF SEWAGE AND SOLID WASTES
(Reproduced from Fig. 1, Ref. 10)

Necessary operations have already been discussed and are assumed to be economically, technically and socially beneficial. Alternatives to vehicular transport are seen to include: (1) the immediate segregation, grinding, and discharge of solid wastes by the use of garbage grinders in the household or building in which the wastes originate; (2) central garbage grinding and sewer transport; (3) use of truck mounted grinders at convenient points in the sewer system, as suggested in Reference 43; and (4) introduction of a dry vacuum system for transport of solid wastes from buildings to central stations, as discussed in Reference 45. Whether the integrated costs of collection of combined refuse and sewage solids would be less than the sum of the costs of separate collection as at present is the decisive question.

A study of the costs of vehicular collection and sewer transport of garbage in 1966 (Ref. 44) led to the conclusion that handling garbage with sewage would cost one quarter to one half that of vehicular collection of garbage if householders are required to purchase and install kitchen garbage grinders.

A comparison of presently conventional collection at Philadelphia, Penna., versus pneumatic transport through a dry vacuum system to four central grinding stations where the wastes would be mixed with sewage, ground, and pumped into a solid-wastes pipeline for transport to a disposal point, led to the following conclusions: (1) based on a comparison of direct costs projected for a 50-year period and on construction of necessary works by present technology, the proposed system would be competitive if the distance to the disposal site were about 50 miles; (2) with assumed moderate improvements in costs and technology, the proposed system would be only slightly more expensive if the distance to the disposal point was short. Not taken into account were the indirect benefits of the proposed system or possible increases in disposal costs by the delivery of a sewage-solid wastes slurry. (Ref. 45).

Mr. John D. Parkhurst, Chief Engineer and General Manager of the County Sanitation Districts of Los Angeles County, replied to an inquiry from the ASCE Project as follows:

> "The addition of refuse to the sewers is not now being practiced nor do we anticipate doing so in the near future. It is doubtful that the handling of ground refuse as sewage sludge will ever be a major factor in the disposal of refuse in Los Angeles County, but it might find some small application in the southernmost areas of the County where landfills are scarce and where sewage will probably continue to receive only primary treatment before discharge to the ocean. Even this is doubtful, however, as more and more effort is devoted to curtailing the discharge of solids to the natural receiving waters."

Conclusion

Based on the available evidence, it would appear that the ASCE Project scheme of grinding and pumping sewage through pressure tubing and conduits could become a physically feasible system of transporting finely ground refuse waste solids provided that suitable heavy-duty grinding devices can be developed and glass and metals are removed from or by-passed within the system; but that the economic feasibility and desirability in terms of costs and benefits remain to be determined.

SECTION XIV

FOLLOW-ON FIELD TESTING

Introduction

The household storage-grinder-pump unit (SGP) developed by the General Electric Company and described in Section V has been tested in the laboratory in relatively short test-runs with what may be considered troublesome constituents of domestic sewage and with sanitary sewage from an industrial plant including cafeteria wastes. The test demonstrated as well as possible the ability of the unit to grind and pump domestic sewage at rates between 15 gpm at atmospheric pressure and 11 gpm at the maximum planned service pressure of 35 psig at the outlet of the unit. The unit has also been tested to insure tentative general compliance with anticipated Underwriters' Laboratories requirements for electrical safety.

Needless to say, responsible manufacturers will submit new products such as the SGP unit to field tests before placing them on the market.

Originally the ASCE Project planned to include a field test of the proposed system in an existing combined sewer district. About a dozen SGP units were to be manifolded via tubing from each household to a common street pressure sewer. Limitations in time and funds were responsible for the omission of this advanced testing program. However, because the SGP unit is the heart of pressurized sewerage physical feasibility for residential service, the New York State Department of Health enthusiastically assumed responsibility for follow-on development (Ref. 47) in a Facilities Demonstration Grant awarded the Department by FWPCA in 1969. Such a follow-on is crucial because all previous attempts to exploit the pressure sewerage principle have been frustrated by the absence of a reliable, thoroughly developed, reasonable unit-cost household storage-grinder-pump unit.

Field Testing of Household Units

The main purposes of "A Pressure System Demonstration" by the New York State Department of Health are to:

(1) provide opportunity for modification of the initial household unit design, as indicated by unexpected field requirements, or by malfunction or by premature wearing out of parts; (2) provide a test of the ruggedness and reliability of the units operating singly and in concert (manifolded to a common street sanitary pressure sewer); (3) provide proof of

the field suitability of the assemblage, which should be regarded as essentially a module of a much larger pressure system; and (4) provide new data which would be invaluable in subsequent pressure system applications.

Specific objectives will include measures to: (1) document the effectiveness of small-diameter non-metallic pressure sewers in carrying routinely the wastewater from a number of residential buildings over an extended period of time, including seasonal changes and prolonged periods of disuse (long weekends, vacations and the like); (2) obtain the operating experience necessary for an evaluation of the effectiveness of individual storage-grinder-pump units by subjecting these prototypes to an extended period of actual use in a significant number of homes where the mechanical performance, use patterns, operating costs and maintenance requirements would be completely monitored; (3) determine through a monitoring program the occurrences and durations of any overflows, either confirming the initial choice of SGP unit pumping rates and storage capacity or showing the need for modification; (4) determine whether or not there is an optimum operating pressure range for this type system which is within or outside the range under consideration (such results would also supply design inputs for the future design of a working system); and (5) characterize by physical and chemical analyses the quality of wastewater produced by such a pressure system and draw conclusions on what, if any, difference would result from transporting such wastewater through a gravity sewer system with disposal in a conventional treatment plant over similar handling of conventional unground wastewater.

The demonstration proposed in the approved Grant Application will include installation of storage-grinder-pump units in twelve residences of close proximity. The pressure tubing from each unit will be connected to a common pressure street sewer. A conventional gravity building service connection will also be installed in each house, to accommodate any overflows that might occur, for example during brief periods when the pressure system might be taken out of service for modification of components. When the demonstration has been completed the residential plumbing will be permanently connected to the gravity building sewer and the pressure system connections will be removed.

The street pressure conduit into which the twelve pressure tubing lines will be joined will discharge at a manhole into the gravity sewerage of the subdivision. An automatic sampling device will be provided at the pressure system outlet to permit characterization of the wastewater. The type of analytical work contemplated includes:

(1) analytical determinations of —

pH
Suspended Solids
Total Solids
Total Volatile Solids
Settleable Solids
  (Relative to time)
BOD_5
COD
Total Nitrogen

Ammonia Nitrogen
Total Phosphate
Chloride
Grease
Sulfide

Relative Stability
Hardness
Detergent (LAS);

(2) a particle size distribution study;

(3) a benchtop study for evaluation of the treatability of ground wastewater; and

(4) a settleability study.

Instantaneously available intelligence will be continuously provided on the operating status of each household unit, e.g., on the incidence and duration of pump operation, and on the occurrence of power outages. It is anticipated that sensors for six such parameters would be connected to each household unit, feeding data through an underground system of control wiring into a central data collection facility installed in a small building or vault at a convenient on-site location. At this center, data are to be recorded automatically on magnetic tape for periodic collection. Subsequent translation and printout of the data in response to a computer program will accomplish the bulk of data reduction, thereby minimizing engineering involvement in routine aspects of the project while assuring that all pertinent data will be systematically and reliably accumulated.

By means of a single leased line, the over-all system status will be continuously displayed at a manned, remote surveillance station, while the individual status of each household unit will be continuously displayed via auxiliary visual indicators at the on-site data center.

It is planned to conduct the demonstration over a period of at least twelve months in order to develop adequate, significant operating data and experience. Including time for final planning and for installation of the SGP units and tubing while the houses are being built, the total time required for the demonstration is estimated at about twenty-one months. The demonstration will take place in the Albany, N.Y. area. (Ref. 48).

Field Demonstration in an Entire Service District

There is widespread conviction that the intensive 12-home module field demonstration under way by the New York State Department of Health should be completed before a full-scale pressure sewer system demonstration is undertaken in a combined sewer service district of several hundred buildings. The probability of a successful large-scale demonstration would thereby be maximized. As implied in Fig. 2 in Section II, experience with a successful full-scale field demonstration will be necessary before the ASCE Project scheme will achieve acceptance for general application by the civil engineering profession at large.

The text of Reference 13 is essentially an ASCE Project annotated check list of matters that should be taken into account in planning a full-scale field demonstration. Its purposes are: to delineate problems that might be encountered in planning, constructing and operating a pressure sewer system; to indicate unknowns and effects currently subject to question; and to suggest minimum required or desirable field measurements, observations, and sampling for an adequate demonstration of the scheme. The major points raised in Reference 13 are summarized in the remainder of this section.

In the implementation of a demonstration project every available means should be exploited to assure that as many buildings as possible in the project area are connected to the demonstration system. Means recommended include an extensive public relations program, public ownership and management of building storage-grinder-pump and comminutor-storage-pump installations, preventive maintenance and inspection by a public agency, adequate stocking of spare parts to minimize down time, and availability of repair service around the clock. Special legal agreements must be effectuated which include consideration of: right of access for inspection and maintenance of building units; allocation of costs; liability for flooding or other damage that might result as a consequence of the demonstration; and restoration of private property should reversion to a gravity system become necessary or desirable. Means should be provided to detect inadvertent and deliberate by-passing of building units, which might defeat the purpose of the scheme.

The demonstration project would provide an opportunity for evaluating the degree of satisfaction of beneficial objectives, particularly improved receiving water quality and elimination of groundwater and surface water from the isolated sanitary sewage. Required are measurements of quality and quantity of combined sewage before separation and of both storm water and sanitary sewage after separation, together with receiving water quality determinations before and after separation. Several monitoring locations will be needed for adequate evaluations. There will be opportunities for careful accounting of construction, operating and all other costs, and of intangible disbenefits such as nuisance and inconvenience.

There has been universal agreement on the need for solids-size reduction prior to pressurization of domestic sewage, to assure a minimization of obstruction and blockage. Despite this precaution and although the criteria for design of street collection systems developed by the ASCE Project are generally considered to be on the safe side, their collective adequacy can be ascertained only in the field. Therefore, means should be incorporated for detecting obstructions so that design criteria and operating procedures can be modified, if necessary, to reduce their occurrence. On the other hand, techniques should be investigated to determine the greatest practicable reach of pressure sewer that can be cleaned because the number and cost of street valves and fittings might be significantly decreased the greater the reach. Field measurements should be made to assess the adequacy of other design criteria, such as minimum solids transport velocity requirements. Alternative conduit layouts should be provided in portions of the demonstration system for evaluation of configuration options. There would also be opportunities for testing the effectiveness of polymer additives in reducing resistance to pipe flow as an alternative to routine solids accumulation removal, or to accommodate individual larger-than-anticipated building loads in lieu of new larger or paralleling mains. A demonstration project would provide a unique opportunity for determining the relative extent of blockage with and without solids-size reduction: grinding could be deferred until the sewage reached the remainder of the system served by grinders or comminutors in individual buildings.

One of the effects on which a demonstration project could provide new information is that of the anaerobic environment that is expected to exist in a pressure sewer system. Some force main failures due to sulfuric acid attacks have occurred. Other effects might be restriction of flow at high system points by accumulated gas despite the presence of air-relief valves or at other interior pipe locations by accumulations of bacterial growths. A major reason for maintaining a system under pressure at all times that would be pressurized at least part of the time is to avoid air entrapment and/or aggravation of liquid-column separation because of resultant amplifications of water-hammer pressures during rapid changes in flow rates. Despite continuous pressurization, gas accumulations might nevertheless aggravate liquid-column separation.

Extensive measurements of flow and pressure will play an important role in the operation and evaluation of a demonstration project pressure sewer system. Additionally, measurements of flows at various points in the system would provide valuable design data presently unavailable and bases for verifying or correcting assumptions on flows used in designing the demonstration system. If water demands and wastewater flows could be measured simultaneously in individual buildings and for groups of buildings, invaluable information would be obtained on relationships between water demand and wastewater production patterns.

One of the objectives of a demonstration project should be to establish procedures for dealing with interruptions of service in a pressure sewer system in a manner that would result in a minimum duration of interruption, minimum property damage and minimum health hazard in the event of sewage flooding.

One version of the ASCE Project scheme included the installation of pressure conduits inside existing combined sewers. It might be possible in a demonstration project to utilize walk-through size combined sewers for field test installations of some of the pressure conduits. Questions that would be investigated are: structural problems encountered in fastening pressure conduits inside sewers of various materials and varying physical condition; problems of installing pressure sewers inside existing combined sewers of various heights; structural integrity of hangers and adjacent sewer walls when exposed to the thrust of storm flows; effect of accumulated debris on the collective hydraulic capacity of the former combined sewer and its inserted conduit; and suitable methods for cleaning former combined sewers containing inserted pressure conduits. Adoption of the pipe-in-a-pipe concept, however, might introduce problems of legal responsibility for damage to sewered structures, for possible flooding and related property damage, and for restoration of property at the termination of the demonstration.

Possibilities for obtaining synergistic benefits by carrying ground solid wastes in pressurized sewer systems have been outlined in Section XIII. Part of the sewerage demonstration project under discussion might be extended to incorporate an investigation of this multiple-purpose service.

It should be noted in closing that the project for field testing of a dozen household units by the New York State Department of Health will yield important initial information on several of the questions that have been raised here, even though their comprehensive resolution will not be possible until a field demonstration is undertaken in a complete combined sewer service district.

SECTION XV

ACKNOWLEDGEMENTS

The American Society of Civil Engineers is greatly indebted to the following organizations and individuals for their assistance and cooperation in pursuit of project studies. Affiliations given were in effect at the time assistance was rendered.

* * * * * * *

Federal Water Pollution Control Administration

Mr. Allen Cywin
Dr. R.N. Kinman
Mr. G.A. Kirkpatrick
Mr. W.A. Rosenkranz

Municipalities and Other Governmental Jurisdictions

Baltimore DPW:	Mr. B. Suwall.
Boston DPW:	Deputy Commissioner E.G.A. Powers; Mr. J.J. Devlin.
Chicago DPW:	Mr. C.J. Keifer.
Cleveland Department of Public Service:	Commissioner J.R. Wolfs; Assistant Commissioner P.F. Nuhn; Mr. G. Newell.
Department of Housing and Urban Development:	Dr. R.M. Michaels.
Detroit Department of Water Supply:	Mr. A.C. Michael; Mr. D.G. Suhre; Mr. J.W. Brown.
District of Columbia, Department Sanitary Engineering:	Director (Retired) R.L. Orndorff; Director N.E. Jackson; Mr. G.J. Moorehead.

Metropolitan Sanitary District of Greater Chicago:	Mr. F. Dalton; Mr. F. Neill.
Milwaukee DPW:	Commissioner H.A. Coetsch; Mr. H. McCullough; Mr. E. Hirsch; Mr. T. Prawdzik.
Minneapolis-St. Paul Sanitary District:	Mr. J.J. Anderson.
New York City DPW:	Mr. M. Lang; Mr. W. Stampe.
New York State Department of Health:	Mr. Dwight F. Metzler; Dr. Leo J. Hetling.
Philadelphia Water Department:	Commissioner S.S. Baxter; Mr. C.F. Guarino; Mr. J.V. Radziul.
Pittsburgh DPW:	Director B. deMelker.
San Francisco DPW:	Director S.M. Tatarian; Mr. A.O. Friedland; Mr. L.A. Vagadori.
St. Louis Metropolitan Sewer District:	Executive Director P.F. Mattei; Mr. E.J.A. Gain.

Consulting Engineers

Black and Veatch:	Mr. R.E. Lawrence.
Brown and Caldwell:	Mr. F.J. Kersnar.
Camp, Dresser and McKee:	Mr. C.A. Parthum; Mr. D.R. Horsefield.
Chas. A. Maguire and Associates:	Mr. K.P. Devenis.
Greeley and Hansen:	Mr. T.M. Niles.
Metcalf and Eddy:	Mr. E.B. Cobb.
Parsons Corporation:	Mr. G.E. Arnold.
Prince Williams Engineering Co.:	Mr. B.C. Burns.
Seico, Inc.:	Mr. G.F. Hendricks.
Williams and Works:	Mr. T.C. Williams.

Universities and Research Organizations

Aerojet-General:	Mr. F. Bowerman.
APWA Research Foundation:	Mr. H.G. Poertner.
Battelle Memorial Institute:	Mr. J.A. Eibling; Mr. R.B. Engdahl.
Cast Iron Pipe Research Association:	Mr. R.G. Dittig.
Central Engineering Laboratories, FMC:	Mr. M.F. Hobbs.
General Electric R. and D. Center:	Mr. K.S. Watson; Mr. R.P. Farrell; Dr. J.S. Anderson; Dr. R. Brooks.
Harvard University:	Dr. H.A. Thomas, Jr.; Dr. G.M. Fair.
Hittman Associates, Inc.:	Mr. J. Rosenblatt.
National Sanitation Foundation:	Mr. R.M. Brown; Mr. C.A. Farish.
Portland Cement Association:	Mr. J. Hendrickson.
The Johns Hopkins University:	Dr. J.C. Geyer; Dr. F.P. Linaweaver, Jr.
The Pennsylvania State University:	Prof. E.R. McLaughlin.
Travelers Research Center:	Dr. P. Bock.
University of Illinois:	Dr. J.M. Robertson.
University of Pennsylvania:	Dr. I. Zandi.

Manufacturers

American-Standard:	Mr. J.W. Schellinkhout.
BIF, A Unit of General Signal Corporation:	Mr. J.R. Daneker.
Carlson and Son:	Mr. N. Roach.

Chicago Pump, Hydrodynamics Division, FMC:	Mr. M.A. Lamb; Mr. D. Hallmark.
Crane Company:	Mr. John H. Redmond.
Dorr-Oliver:	Mr. R.P. Borden.
Fairbanks-Morse:	Mr. R.R. Bridge.
Hays Manufacturing Company:	Mr. L.L. Buzzard.
Interpace:	Dr. J.T. McCall.
Johns-Manville:	Mr. J.E. Parkinson; Mr. H.J. Kazienko.
Kaiser Aluminum:	Mr. R.H. Vaterlaus.
Liljendahl System:	Mr. B.C. Hryniewicz.
M.A. Clift and Associates:	Mr. M.A. Clift.
Mueller Company:	Mr. H.T. Huffine.
Westinghouse Electric:	Mr. G.S. McCloy.
Worthington Corporation:	Mr. D.L. Gallagher.

Final Report Typing

Mrs. Jan Donker.

ASCE COMBINED SEWER SEPARATION PROJECT

ASCE URBAN HYDROLOGY RESEARCH COUNCIL

Stifel W. Jens, Chairman

PROJECT STEERING COMMITTEE

Vinton W. Bacon
Dr. Morris M. Cohn
Dr. Gordon M. Fair, Chairman
Dr. John C. Geyer
Richard Hazen
Martin Lang
S.W. Steffensen

AMERICAN SOCIETY OF CIVIL ENGINEERS

Dr. William H. Wisely, Executive Secretary

PROJECT STAFF

Murray B. McPherson, Project Director
Lincoln W. Ryder, Consulting Editor
Donald C. Taylor, Project Administration
L. Scott Tucker, Deputy Project Director
Donald H. Waller, Deputy Project Director

SECTION XVI

BIBLIOGRAPHY

Text References

Ref. No. Title

1. "Outline Description of ASCE Project on Separation of Sanitary Sewage from Combined Systems of Sewerage," Tech. Memo. No. 1, ASCE Project, Feb., 1966.

2. Tucker, L.S. "Sewage Flow Variations in Individual Homes," Tech. Memo. No. 2, ASCE Project, Feb., 1967.

3. Waller, D.H., "Experience with Grinding and Pumping of Sewage from Buildings," Tech. Memo. Nos. 3 and 3A, ASCE Project, May, 1967 and March, 1968.

4. Hallmark, D.E., and Hendrickson, J.G., Jr., "Study of Approximate Lengths and Sizes of Combined Sewers in Major Metropolitan Centers," Tech. Memo. No. 4, ASCE Project, May, 1967.

5. Tucker, L.S., "Pressure Tubing Field Investigation," Tech. Memo. No. 5, ASCE Project, Aug., 1967.

6. Tucker, L.S. "Hydraulics of a Pressurized Sewerage System and Use of Centrifugal Pumps," Tech. Memo No. 6, ASCE Project, Nov., 1967.

7. McPherson, M.B., Tucker, L.S., and Hobbs, M.F., "Minimum Transport Velocity for Pressurized Sanitary Sewers," Tech. Memo. No. 7, ASCE Project, Nov., 1967.

8. McPherson, M.B., "Domestic Sewage Flow Criteria for Evaluation of Application of Project Scheme to Actual Combined Sewer Drainage Areas," Tech. Memo. No. 8, ASCE Project, Nov., 1967.

9. Waller, D.H., "Peak Flows of Sewage from Individual Houses," Tech. Memo. No. 9, ASCE Project, Jan., 1968.

10. Waller, D.H., "An Examination of the Benefits and Disadvantages of the Project Scheme with Respect to the Disposal of Solid Wastes," Tech. Memo. No. 10, ASCE Project, Feb., 1968.

Text References (continued)

Ref. No.	Title
11.	Daneker, J.R., and Frazel, W.H., "Control Techniques for Pressurized Sewerage Systems," Tech. Memo. No. 11, ASCE Project, March, 1968.
12.	Waller, D.H. "Non-Mechanical Considerations Involved in Implementing Pressurized Sewerage Systems," Tech. Memo. No. 12, ASCE Project, May, 1968.
13.	Waller, D.H., "Special Requirements for a Full Scale Field Demonstration of the ASCE Combined Sewer Separation Project Scheme," and Appendix "Combined Sewer Separation on Private Property," Tech. Memo. No. 13 with Appendix, ASCE Project, June, 1968.
14.	Tucker, L.S., "Routing of Flows in Sanitary Sewerage Systems," Tech. Memo. No. 14, ASCE Project, July, 1969.
15.	McPherson, M.B., "ASCE Combined Sewer Separation Project Progress," Conference Preprint 548, ASCE National Meeting on Water Resources Engineering, New York, N.Y., Oct., 1967; and Civil Engineering, Dec., 1967.
16.	"Separation of Combined Wastewater and Storm Drainage Systems, San Francisco Study Area," (Task 4), Brown and Caldwell, Consulting Engineers, San Francisco, Cal., Sept., 1968.
17.	"Combined Sewer Separation Project Report on Milwaukee Study Area," (Task 4), Greeley and Hansen, Consulting Engineers, Chicago, Ill., Dec., 1968.
18.	"Report on Pressure Sewerage System, Summer Street Separation Study Area, Boston, Mass.," (Task 4), Camp, Dresser & McKee, Consulting Engineers, Boston, Mass., Sept., 1968.
19.	Farrell, R.P., Anderson, J.S., and Setser, J.L., "Sampling and Analysis of Wastewater from Individual Homes," (Task 2), 67-MAL-3, General Electric Co., Water Management Laboratory, Major Appliance and Hotpoint Division, Appliance Park, Louisville, Ky., March, 1967.
20.	Farrell, R.P., "Long-Term Operation of Wastewater Observation Stations," (Task 2), S-68-1064, General Electric Co., Research and Development Center, Schenectady, N.Y., Apr., 1968.

Text References (continued)

Ref. No.	Title
21.	Farrell, R.P., "Advanced Development of Household Pump-Storage-Grinder Unit," (Task 6), S-69-1038, General Electric Co., Research and Development Center, Schenectady, N.Y., Dec., 1968.
22.	Hobbs, M.F., "Relationship of Sewage Characteristics to Carrying Velocity for Pressure Sewers," (Task 5), R-2598, Environmental Engineering Department, Central Engineering Laboratories, FMC Corporation, Santa Clara, Cal., Aug., 1967.
23.	Bowen, R.N., and Havens, J.G., "Report to ASCE Combined Sewer Separation Project on FWPCA Contract No. 14-12-29," (Tasks 7 and 9), National Sanitation Foundation, Ann Arbor, Michigan, Dec., 1967.
24.	Kazienko, H.J., "Report to ASCE Combined Sewer Separation Project on FWPCA Contract No. 14-12-29, Develop and Field Test Method of Installing Pressure Conduits in Combined Sewers," (Task 7), Johns-Manville Products Corporation, Research and Engineering Center, Manville, New Jersey, Dec., 1968.
25.	Robertson, J.M., "Turbulent Friction in Eccentric Annular Conduits-Effect of Inserted Pipe on Flow Capacity of Sewers," (Task 12), Report No. 310, Dept. of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill., March, 1968.
26.	Nelson, A.R. and Robertson, J.M., "Analytical Studies of Turbulent Friction in Annular Conduits-Effect of Inserted Pipe on Flow Capacity of Sewers," (Task 12), Report No. 321, Dept. of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill., Nov., 1968.
27.	*Problems of Combined Sewer Facilities and Overflows*, WP-20-11, by The American Public Works Association, Project 123, for the U.S. Dept. of the Interior, Federal Water Pollution Control Administration, Dec., 1967.
28.	*Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems*, Publication No. 1246, Information Branch, Div. of Water Supply and Pollution Control, U.S. Public Health Service, Washington, D.C., Nov., 1964.
29.	"Report on Phase One, Residential Water Use Project," Dept. of Environmental Engineering Science, The Johns Hopkins Univ., Baltimore, Md., Oct., 1963.

Text References (continued)

Ref. No. Title

30. Thomas, R.E. and Bendixen, T.W., "Domestic Water Use in Suburban Homes," Final Report to the F.H.A., from U.S. Public Health Service Taft Sanitary Engineering Center, Cincinnati, Ohio, June, 1962.

31. Orndorff, J.R., "Domestic Water Use Differences in Individual Well and Public Water Supplies," Report III, Phase 2 of the Residential Water Use Research Project, Dept. of Environmental Engineering Science, The Johns Hopkins Univ., Baltimore, Md., June, 1966.

32. Linaweaver, F.P., Jr., Geyer, J.C., and Wolff, J.B., "Report V, Phase 2, Final and Summary Report on the Residential Water Use Project," Dept. of Environmental Engineering Science, The Johns Hopkins Univ., Baltimore, Md., June, 1966.

33. Wolff, J.B., Linaweaver, F.P., Jr., and Geyer, J.C., "Water Use in Selected Commercial and Institutional Establishments in the Baltimore Metropolitan Area," Dept. of Environmental Engineering Science, The Johns Hopkins Univ., Baltimore, Md., June, 1966.

34. *Design and Construction of Sanitary and Storm Sewers*, ASCE Manuals of Engineering Practice No. 37, WPCF Manual of Practice No. 9, Prepared by a joint Committee of the American Society of Civil Engineers and the Water Pollution Control Federation, New York, N.Y., 1969.

35. *Environmental Pollution, A Challenge to Science and Technology*, Report of the Subcommittee on Science, Research and Development to the Committee on Science and Astronautics, U.S. House of Representatives, 89th Congress, Second Session, 1966.

36. *Waste Management and Control*, National Academy of Sciences, National Research Council, Publication 1400, Washington, D.C., 1966.

37. Gannon, J.J., and Streck, L., "Current Developments in Separate versus Combined Storm and Sanitary Sewage Collection and Treatment," School of Public Health, Univ. of Michigan, Ann Arbor, Mich., June, 1967.

Text References (continued)

Ref. No. Title

38. Paone, J., Bruce, W.E. and Morrell, R.J., *Horizontal Boring Technology: a State-of-the-Art Study*, Bureau of Mines Information Circular 8392, U.S. Dept. of the Interior, Bureau of Mines, Washington, D.C., Sept. 1968.

39. Auld, D.V., "Protecting the Potomac at Washington," *J.WPCF*, Vol. 37, No. 3, Mar., 1965.

40. Tooley, L.J., "All Homes in Shorewood Hills Village Will Grind Their Garbage," *The American City*, Feb., 1953.

41. Clift, M.A., "Experience with Pressure Sewerage," *J. San. Eng. Div.*, ASCE Proc., SA5, No. 6150, Oct., 1968.

42. *Refuse Disposal*, American Public Works Ass'n., 1966 (Chapt. 7 — "Grinding Food Wastes.").

43. Golueke, C.G., and McGauhey, P.H., "Comprehensive Studies of Solid Wastes Management," Univ. of California, Berkeley, Cal., 1967.

44. Clark, C.M., Stroud, L.H., and Watson, K.S., "Home Disposers versus Surface Collection — a Comparative Cost Analysis," *Water and Wastes Engineering*, Sept., 1966.

45. Zandi, I., and Hayden, J.A., "Collection of Municipal Solid Wastes in Pipelines," Presented at ASCE Transportation Conference, San Diego, Cal., Feb., 1968.

46. Wolfe, H.B., and Zinn, R.E., "Systems Analysis of Solid Waste Disposal Problems," *Public Works*, Sept., 1967.

47. "Metzler Leads a Pure Water War," *Engineering News-Record*, Sept. 11, 1969.

48. Cywin, Allen, and Rosenkranz, W.A., "Storm and Combined Sewer Research and Development," Meeting Preprint 1039, ASCE Annual and Environmental Meeting, Chicago, Ill., Oct., 1969.

General References

Federal Government

A National Policy for the Environment, Senate Interior and Insular Affairs Committee, and Committee on Science and Astronautics of House of Representatives, Ninetieth Congress, Oct., 1968; and Colloquium, July, 1968.

"Pertinent Areas for Research and Development, Storm and Combined Sewer Pollution Control," FWPCA, U.S. Dept. of Interior, Washington, D.C., July, 1968 (mimeo).

"Research, Development and Demonstration Projects," Vol. 1, Div. of Applied Science and Technology, FWPCA, U.S. Dept. of Interior, Washington, D.C., Jan., 1969.

"Selected Urban Stormwater Runoff Abstracts," for FWPCA, U.S. Dept. of Interior, Washington, D.C., by the Franklin Institute Research Laboratories, Science Information Services, Contract 14-12-467, Jan., 1969.

Reed, P.W., "Control of Pollution from Combined Sewer Systems," Division of Water Supply and Pollution Control, U.S. Dept. of Health, Education and Welfare, Washington, D.C., Aug., 1965.

National Professional Society Reports

"A Study of Sewage Collection and Disposal in Fringe Areas," Progress Report from Committee on Public Health Activities of the Sanitary Engineering Division, J. San. Eng. Div., ASCE Proc., 84: SA2, Paper No. 1613, 1958.

"Background on Water Pollution, Manual for Municipal, State and Federal Planners," National Water Institute, Water and Wastewater Equipment Manufacturers Association, New York, N.Y., Feb., 1968.

"Minimum Velocities for Sewers," J. BSCE, 29:286, 1942.

Individual Authors

Akerlindh, G., "Permissible Water Pollution at Combined Sewer Overflows," Sewage Works Journal, 21:6, June, 1949.

Anderson, J.S., and Watson, K.S., "Patterns of Household Water Usage," J. AWWA, Oct., 1967.

General References (continued)

Bacon, V., Leland, R., and Sosewitz, B., "Separation of Sewage from Storm Water," Paper No. 12, Inst. of Civil Engineers, England, May, 1967.

Baker, R.J., "Package Aeration Plants in Florida," J. San. Eng. Div. ASCE Proc., 88:SA6, Nov., 1962.

Burm, R.J., Krawczyk, D.F., and Harlow, G.L., "Chemical and Physical Comparison of Combined and Separate Sewer Discharges," J. WPCF, 40:1, Jan., 1968.

Burm, R.J., and Vaughn, R.D., "Bacteriological Comparison Between Combined and Separate Sewer Discharges," J. WPCF, 38:3, Mar., 1966.

Camp, T.R., "Overflows of Sanitary Sewage from Combined Sewerage Systems," Sew. and Ind. Wastes, Apr., 1959.

Camp, T.R., "The Problem of Separation in Planning Sewer Systems," J. WPCF, Vol. 38, No. 12, Dec., 1966.

Clark, C.M., Stroud, L.H., and Watson, K.S., "Home Disposers versus Surface Collection," Water and Wastes Engineering, Sept., 1966.

Cohn, M.M., "The Disposal of Sewage and Garbage — Related Municipal Functions," Sew. Wks. Journal, 10:1, 1938.

Cosens, K.W., "Design Factors in Dual Disposal," Sew. and Ind. Wastes Eng., Jan., 1950.

Cosens, K.W., "Household Garbage Grinders — How They Affect Sewers," American City, Sept., 1949.

Cosens, K.W., and Hanemann, E.J., "Sewer Velocity Required for Kitchen — Ground Waste," American City, Jan., 1949.

Davidson, R.N., and Gameson, A.L.H., "Field Studies on the Flow and Composition of Storm Sewage," Water Pollution Research Laboratory, (British, undated, about 1965).

Dobbins, W.E., "Quantity and Composition of Sewage Overflows," N.Y. ASCE Met. Sect. Symposium, Apr., 1962.

Dunbar, D.D., and Henry, J.G.F., "Pollution Control Measures for Stormwaters and Combined Sewer Overflows," J. WPCF, Vol. 38, No. 1, Jan., 1966.

Fair, G.M., Geyer, J.C., and Okum, D.A., Water Supply and Wastewater Removal, Water and Wastewater Engineering, Vol. 1, John Wiley and Sons, New York, N.Y., 1966.

Firstman, S.I., "Advanced Sewage Systems for Housing Cost Reduction," Rand Corporation, #D-17170-PR, May, 1968.

Hunter, R.B., Methods of Estimating Loads in Plumbing Systems, N. Bu. Stds., BMS Report 65, 1940.

Linaweaver, F.P., Jr., and Geyer, J.C., "Use of Peak Demands in Determination of Residential Rates," J. AWWA, Vol. 56, No. 4, Apr., 1964.

McKee, J.C., "Loss of Sanitary Sewage Through Storm Water Overflows," J. BSCE, 34, Apr., 1947.

Palmer, C.L., "The Pollutional Effects of Storm-Water Overflows from Combined Sewers," Sew. and Ind. W., Vol. 22, No. 2, Feb., 1950.

Poertner, H.G., Anderson, R.L., and Wolf, K.W., Urban Drainage Practices, Procedures and Needs, American Public Works Assn., Proj. 119, APWA Research Fdn., Spec. Rep. 31, Dec., 1966.

Rawn, A.M., "Some Effects of Home Garbage Grinding Upon Domestic Sewage," American City, Mar., 1951.

Rath, C.A., and McCauley, R.F., "Deposition in a Sanitary Sewer," Water and Sewage Works, May, 1962.

Riis-Carstensen, E., "System Design and Operation to Minimize Pollution, (Buffalo)," Art. 6, "Treatment of Storm Sewage Overflow," N.Y. ASCE Met. Sect. Symposium, Apr., 1962.

Romer, H., and Klashman, L.M., "Influence of Combined Sewers on Pollution Control," Public Works, Oct., 1961.

Romer, H., and Klashman, L.M., "How Combined Sewers Affect Water Pollution," Public Works, Mar., 1963.

Rousculp, J.A., "Storage Basins as a Supplement to Storm Sewer Capacity," Civil Engineering, Nov., 1940.

Shifrin, W.G., and Horner, W.W., "Effectiveness of the Interception of Sewage-Storm Water Mixtures," J. WPCF, Vol. 38, No. 6, June, 1961.

Stegmaier, R.B., "Storm-water Overflows," Sewage Works Journal, 14:6, June, 1942.

Symonds, G.E., "Pumps and Pumping," Water and Wastes Engineering, Sept., 1966.

General References (continued)

Thomas, H.A., Jr., Coulter, J.B., Bendixen, T.W., and Edwards, A.B., "Technology and Economics of Household Sewage Disposal Systems," J. WPCF, 22:2, Feb., 1960.

Watson, K.S., "Water Requirements of Dishwashers and Food Waste Disposers," J. AWWA, 55:5, May, 1963.

Watson, K.S., Farrell, R.P., and Anderson, J.S., "The Contribution from the Individual Home to the Sewer System," J. WPCF, Sept., 1966.

Weller, L.W., and Nelson, M.K., "Diversion and Treatment of Extraneous Flows in Sanitary Sewers," J. WPCF, 37:3, Mar., 1965.

Wolff, J.B., Linaweaver, F.P., Jr., and Geyer, J.C., "Water Use in Selected Commercial and Institutional Establishments in the Baltimore Metropolitan Area," Dept. of Environmental Engineering Science, The Johns Hopkins Univ., Baltimore, Md., June, 1966.

Wolff, J.B., "Peak Demands in Residential Areas," J. AWWA, Vol. 53, No. 10, Oct., 1961.

Wraight, F.D., "Garbage Grinder Experiences, Jasper, Indiana," Sew. and Ind. Wastes, Jan., 1956.

SECTION XVII

PATENT

Jan. 30, 1968 G. M. FAIR **3,366,339**

CONVERTED SEWER SYSTEM

Filed Nov. 26, 1965

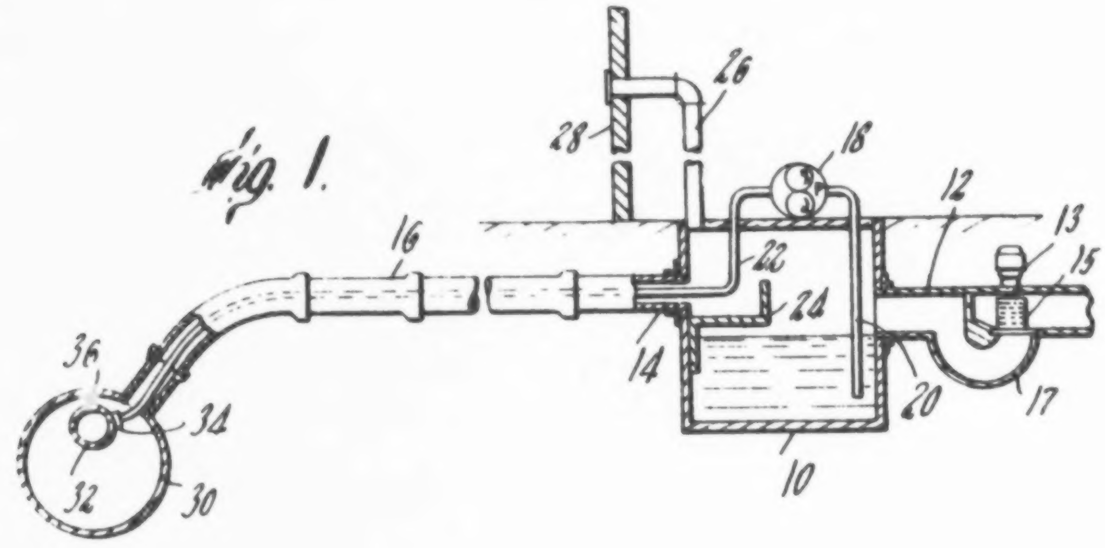


Fig. 1.

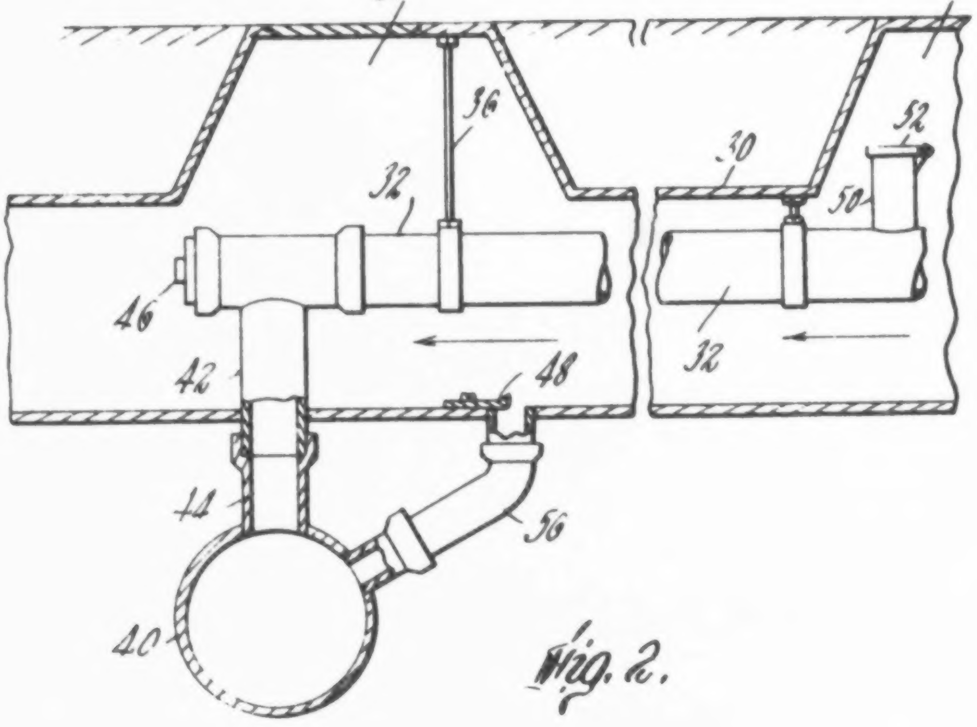


Fig. 2.

United States Patent Office

3,366,339

Patented Jan. 30, 1968

3,366,339

CONVERTED SEWER SYSTEM

Gordon M. Fair, 29 Robinson St.,
Cambridge, Mass. 02138

Filed Nov. 26, 1965, Ser. No. 509,711
The entire term of the patent has been
dedicated to the public
6 Claims. (Cl. 241—101)

This invention relates to sewage systems and particularly to a novel system for separating sanitary sewage (domestic, mercantile, industrial) from stormwater in previously combined systems of sewerage. The term "sanitary sewage" is used to designate water discharged from water fixtures and collected as wastewater after serving its primary purpose, as well as water serving the purpose of carrying away waste matters from households, mercantile, commercial and industrial establishments.

The U.S. Department of Health, Education, and Welfare, in its recent publication, "Pollutional Effects of Stormwater and Overflow from Combined Sewer Systems," November 1964, estimates that 59 million people in the United States live in communities with combined systems of sewerage. The main and branch sewers of such systems are usually designed to accommodate not only sanitary sewage but also the runoff from rainstorms. Because it is impractical to carry the occasional stormwater-swollen flows, which are a great many times the volume of sanitary sewage, to treatment plants and treat them before discharging them into nearby watercourses such as rivers, lakes, and tidal estuaries, intercepting sewers built to intercept sanitary sewage flows before they can spill into water courses are seldom designed for a flow capacity much beyond the maximum dry weather flow. This dry weather flow normally consists only of the sanitary sewage and water leaching into sewers from wet ground, or coming from street-washing, lawn-sprinkling, and other dry-weather operations. Intercepters are seldom given a flow capacity in excess of 3 times the dry-weather flow in United States practice. At times of storms, the excess flow above the intercepter capacity is overflowed, usually directly to a watercourse. This overflow contains raw sewage and the amount of raw sewage discharged in this manner into the streams may, in the course of a year, amount to as much as or more than 5% of the total annual sanitary sewage.

The extensive pollution of waters from this source is a serious problem to which, the above publication concludes, the ultimate answer is complete separation of sanitary sewage flow from stormwater flow. When new sewage disposal systems are being installed the provisions of completely separate lines for sanitary sewage leading to the treatment or disposal works and for stormwater leading to the watercourse is economically feasible and modern systems are normally of this type. However, the provision of a conventional separate sanitary sewage system in communities presently employing a combined system would be tremendously expensive, estimated in the above publication to cost the nation 20 to 30 billion dollars.

The object of this invention is to provide a novel apparatus system by which combined sewage systems may be converted to separate sanitary sewage and stormwater disposal systems at greatly reduced cost and without the inconvenient and costly opening up of streets and sidewalks as required by prior proposals.

In accordance with the invention, each building having an existing sanitary sewage connection to a combined sewer is provided with a tank, usually in the basement, in which all sanitary sewage from the building is received. The tank is provided with a pump or pumping system, preferably including or preceded or followed by a shredder or system of shredding. The pump or pumping system forces the sewage through a pipe which extends through the existing house or other building sewer conduit which is connected to the combined sewer, and is of substantially smaller diameter than such conduit. This pipe is preferably made of flexible plastic or otherwise so constructed that it may be fished through the existing conduit to the sewer and will accommodate the pressurized flow of sewage from the pump. Within the combined sewer there is laid a sanitary sewage receiving pipe to which the sanitary sewage discharge pipe from the pump of each unit served by the sewer pipe is connected. This receiving pipe is of a construction such as asbestos cement suitable for containing pressurized flow of sewage and of sufficient diameter to contain the sanitary sewage flow from all sources connected thereto, but of substantially smaller diameter than the existing combined sewer pipe or conduit within which it is laid. The sanitary sewage receiving pipe within the existing combined sewer extends to the nearest intrecepter leading to the sewage treatment or disposal works and preferably discharges into such intercepter, although it may, if desired, be continued through such intercepter to the works. Such receiving pipe may be laid, hung or otherwise supported within the existing combined sewer readily and without the necessity of opening up the streets or sidewalks above the sewer. If the sewer at the point at which the existing sewage conduit discharges to it is too small to permit access of a workman to connect the sanitary sewage discharge pipe from the unit to the receiving pipe within the sewer, the discharge pipe is continued within the sewer and fished to the nearest manhole, normally not more than 200 feet away, where the connection may be readily made.

It will be seen that the invention makes possible a completely separate sanitary sewage disposal system which may be provided within an existing combined sewer system without opening up the ground over the existing system. This is accomplished without the necessity of new piping other than a single, relatively small sewer pipe in each existing combined sewer line for receiving the sanitary sewage from each source discharging to said line and which need extend only to the nearest intercepter leading to the sewage treatment plant, and the relatively small pipe extending from each source through the existing building sewer conduit to the sanitary (small) sewer pipe in each existing combined sewer. The saving in cost thereby effected, as compared with laying a new sanitary sewer system in the conventional way from each unit to the treatment plant, far exceeds the cost of the additional equipment which such a conventional separate gravity flow system would not require, such as the receiving tank, pump and shredder. In addition, the pressurized system which the invention provides at much lower cost, has distinct advantages over a gravity flow system.

To the cost saving above mentioned should be added the smaller diameter of piping required as compared with a separate gravity system and the fact that, due to its protection by housing within an existing sewer system, it can be of less costly construction than that of piping which is laid directly under ground. For example, the sanitary sewage piping according to this invention may be of the order of ⅛ to ¼ the diameter of the existing sewer connections and much of it may be made of inexpensive plastic material.

At times of storms my system disposes of the stormwater to the watercourses as before but free of sanitary sewage or with not more than a trace thereof which may be occasioned by overflow from safety valves or other control outlets provided in the pressurized sanitary sewage system or from overflow devices provided in the tank within the premises.

The invention will be further described in connection with the accompanying drawing wherein:

FIG. 1 illustrates in vertical cross-section a portion of a house or similar unit and sewer connections to it which have been modified according to the invention to convert the system from combined to separated sanitary sewage and stormwater disposal; and

FIG. 2 is a view similar to FIG. 1 of the existing combined sewer now serving as a storm sewer and the sanitary sewer showing a junction with an intercepter leading to the sewage treatment or disposal works, and also showing a safety valve in the pressurized line.

Referring to FIG. 1 of the drawing, the sewer connections for only one house or similar unit are shown, it being understood that such connections are essentially duplicated for each unit served by the sewer pipe up to the nearest intercepter leading to the sewage treatment plant.

Referring to the drawing, the sanitary sewage collecting tank for the house or other unit is shown at **10** located at a low level such as on or below the basement floor, having an inlet **12** to the existing sewage outflow pipe from the unit and an overflow outlet **14** connected to the usually underground conduit **16** which connects the unit to the existing combined sewer pipe **30**. Inlet **12** is shown as preceded by a shredder **13** provided with a cutting screen **15** which discharges the shredded sewage through elbow **17** to inlet **12**. Above tank **10** is located a pump **18**, diagrammatically indicated as a gear pump, the motor for which is not shown. The pressure required of the pump is not great, and may be such as to produce a flow rate of the order of six feet per second as compared with the normal gravity flow rate of the order of one to four feet per second.

The pump **18** may be a gear pump as indicated, or may be a centrifugal or other mechanical pump or an ejector supplied with compressed air from a compressor, such ejector being advantageous from the standpoint that the compressed air injects oxygen into the sewage which aids in keeping it fresh in the closed pressurized system. The pump may be a system of pumps in series or in parallel. The shredder may be of any suitable type and may have a single rotary cutting screen or similar device or may be a system of such devices arranged in series or in parallel. When a shredder or shredder system is used it preferably precedes the pump or pumping system to avoid fouling the pump or pumps with non-comminuted sewage, but it may follow the pump where this is not a problem. The shredder may be dispensed with in cases where the maximum particle size of the sewage is not such as would be expected to cause plugging but should otherwise usually be employed. The shredder or shredder system may be located in line **20** immediately preceding pump **18** and be operated by the same motor as the pump, as may be preferable with smaller units.

The inlet to the pump as shown is through pipe **20** which extends close to the bottom of the tank and the pump discharges to a pipe **22** which is of smaller diameter than conduit **16** and extends into tank **10** and out through conduit **16** to the main sewer pipe **30**. As previously explained, pipe **22** is of a construction such that it can be finished through conduit **16** to main sewer pipe **30** without the necessity of opening the ground above the conduit or sewer pipe, and may be preferably of flexible plastic or latex composition similar to that utilized in garden hose. A trough **24** supported on the wall of tank **10** below outlet **14** extends above the outlet to provide an emergency overflow outlet for the sewage to conduit **16** in the event tank **10** should for some reason fill above its anticipated maximum contents level. If the system is not adequately vented through the existing combined sewer and pipes **16** and **12**, an air vent and inlet pipe **26** may be provided which extends from the top of tank **10** to some point above ground as in the building wall **28**, where it may have shielded exposure to the atmosphere. Pipe **26** may also have a branch connection to the inlet side of comminuter **13** in order to insure complete venting of the system.

Tank **10** will usually be equipped with controls (not shown) for governing the operation of the pump, such as one or more float valves or sensors for starting the unit when the contents of the tank reach a desired maximum storage level and stopping it when the tank is emptied to a desired minimum level. Controls for operating the shredder during times of flow, also not shown, will also normally be provided. There may also be included time controls which permit the pump to operate only at certain times unless an emergency level is reached in the meantime. By staggering operating times of the various units served by main sewer pipe **30** the daily sewage flow to the treatment plant can be regularized and overloads prevented. If the pump **18** is a gear pump as shown, it will prevent backflow from pipe **22**. If another type of pump is used which does not prevent backflow, a backflow control device such as a check valve will ordinarily be provided for the purpose.

It should be noted that conduit **16**, except for the small volume thereof occupied by pipe **22**, is now available to conduct to sewer pipe **30** waste water from roofs and gutters, and from area and cellar drains and the like. These may now be safely connected to this conduit whereas in the former combined system this was not normally feasible due to the danger of overloading the conduit and interfering with sewage flow from the house or other unit in times of storms. The end of conduit **16** in tank **10** may be provided with the usual check valve (not shown) for preventing backflow therefrom into the tank.

Within main sewer pipe **30** is located the sanitary sewage receiving pipe **32** to which pipe **22** is connected at **34**. Pipe **32** is made of material suitable for pressurized flow at the pressures involved, such as asbestos cement. Pipe **32** is shown suspended by hangers as at **36** within pipe **30** but where access to the interior of pipe **30** may not readily be had, pipe **32** may be simply pushed or pulled through and laid in pipe **30** from manhole to manhole. Likewise, when access may not readily be had for connecting pipe **22** to pipe **32** at the point of entry of pipe **22** into sewer **30**, pipe **22** may be fished to the nearest manhole and the connection made there.

FIG. 2 shows at the left the sewer system of FIG. 1 at the junction with the nearest intercepter **40**, which is a gravity flow pipe discharging to the sanitary sewage treatment or disposal works. Pressure pipe **32** terminates at this junction, discharging through connecting pipe **42**, into an inlet **44** to interceptor **40**. A cleanout plug **46** is desirably provided at the end of pipe **32**. Sewer pipe **30** continues beyond the junction to discharge as before to the existing outfall at times when it contains stormwaters received from its source inlets.

Normally, it is desirable to provide a connection between intercepter **40** and main sewer **30** so that any emergency sanitary sewage overflows from the pressurized sanitary sewage system will transfer to the intercepters. The old connections may be retained or new connections provided. In the instance illustrated in the drawing existing connections between main sewer and intercepter of so-called "leaping weir" type are retained, tho adjustable weir plate **48** thereof being left open sufficiently to cause the small amount of dry weather flow that may be anticipated, due to leakages into the main sewer system and possible emergency overflow discharge thereto from the pressure system, to pass downwardly through inlet **56** to intercepter **40**. Stormwater flows will in most part overflow the weir and pass on to the outfall, as indicated by the upper arrows. Desirably ready access will be provided to the connections to the intercepter, as by the manhole compartment **31** shown.

It will be understood that pressure pipe **32** may be provided at suitable intervals with emergency overload relief valves which will discharge into sewer pipe **30** to such extent as necessary to remove temporary overloads. Such a valve is shown at the right in FIG. 2 in the form of a vertically dispose pipe **50** opening at its base into pressure pipe **32** and closed at the top by a hinged cover **52**. The upper part of pipe **50** extends into a compartment **54** which rises above the main sewer pipe **30** and may conveniently be a manhole. Under normal pressure and flow the sanitary sewage in pipe **32** will not rise to the top of pipe **50** and cover **52** will remain closed. If sufficient back pressure should develop in the pressure system due to overload or plugging, the sanitary sewage will rise to the top of pipe **50** and force open cover **52**, escaping into compartment **54** and to main sewer pipe **30** until the condition is relieved, whereupon the cover **52** again closes under its weight. At times of storms the stormwater will not ordinarily rise above the cover **52** and so the relief system remains operable at such times.

While it will usually be satisfactory and less expensive to permit the sanitary sewage to discharge from the pressure pipe system into the existing intercepter system as shown, it may be desirable in some instances to continue the pressure system within the intercepters to the sewage treatment or disposal works.

I claim:

1. A sewage system for separately conducting stormwater to an outfall and sanitary sewage to a sewage treatment or disposal works comprising a first system of piping leading to an outfall, having inlets for stormwater and also having pipe connections from sources of sanitary sewage such as buildings, a second system of piping of substantially smaller diameter than the piping of said first system and housed within it for receiving pressurized sanitary sewage flow, said second system being normally closed to said outfall and having connections leading to said works, said second system being connected to receive pressurized sanitary sewage flow from said sources of sanitary sewage by means of pipe connections extending through said pipe connections of said first piping system, said sources of sanitary sewage including a storage tank for the sewage and pump means connected to withdraw sewage from said tank and to discharge it under pressure through said pipe connections of said second piping system.

2. A sewage system according to claim **1** wherein said first system of piping includes intercepters leading to said works and said second system of piping discharges to said intercepters.

3. A sewage system according to claim **1** which includes means for shredding the sewage before it is discharged into said second piping system.

4. A sewage system according to claim **1** wherein said pipe connections of said second piping system from said sources of sanitary sewage are of flexible material such that they may be readily fished through the piping of said first piping system.

5. A sewage system according to claim **1** wherein said tank is provided with means permitting emergency overflow to said pipe connections of said first piping system.

6. A sewage system according to claim **1** wherein said second piping system is provided with means permitting emergency overflow from said second piping system to said first piping system.

References Cited

UNITED STATES PATENTS

2,852,313	9/1958	Mickel	302—14
3,239,849	3/1966	Liljendahl	302—14

GERALD A. DOST, *Primary Examiner.*

SECTION XVIII

GLOSSARY*

BOD — (1) The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater strength.

branch sewer — A sewer that receives wastewater from a relatively small area and discharges into a main sewer serving more than one branch-sewer area.

building sewer — In plumbing, the extension from the building drain to the public sewer or other place of disposal.

coliform-group bacteria — A group of bacteria predominantly inhabiting the intestines of man or animals but also occasionally found elsewhere.

combined sewer — A sewer intended to receive both wastewater and storm or surface water.

combined wastewater — A mixture of surface runoff and other wastewater such as domestic or industrial wastewater.

comminuted solids — Solids which have been divided into fine particles.

contamination — Any introduction into water of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the water unfit for its intended use.

diverting weir — A weir placed in a combined sewer to divert storm flow from the normal dry-weather direction.

dry-weather flow — The flow of wastewater in a combined sewer during dry weather. Such flow consists mainly of wastewater, with no storm water included.

force main — A pressure pipe joining the pump discharge at a wastewater pumping station with a point of gravity flow.

hydraulic grade line — A hydraulic profile of the piezometric level of water at all points along a line. In an open channel, it is the free water surface.

(*: From Glossary: Water and Wastewater Control Engineering, ASCE, WPCF, AWWA, APHA, In Press) industrial wastes — The liquid wastes from industrial processes, as distinct from domestic or sanitary wastes.

infiltration — The quantity of groundwater that leaks into a pipe through joints, porous walls, or breaks.

intercepting sewer — A sewer that receives dry-weather flow from a number of transverse sewers or outlets and frequently additional predetermined quantities of storm water (if from a combined system), and conducts such waters to a point for treatment or disposal.

lateral sewer — A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it.

main sewer — (1) In larger systems, the principal sewer to which branch sewers and submains are tributary; also called trunk sewer. In small systems, a sewer to which one or more branch sewers are tributary. (2) In plumbing, the public sewer to which the house or building sewer is connected.

outfall sewer — A sewer that receives wastewater from a collecting system or from a treatment plant and carries it to a point of final discharge.

outlet — Downstream opening or discharge end of a pipe.

overflow weir — Any device or structure over which an excess wastewater beyond the capacity of the conduit is allowed to flow or waste.

pollution — A condition created by the presence of harmful or objectionable material in water. Also see contamination.

regulator — A device for regulating the diversion of flow in combined sewers.

sanitary sewer — A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground-, storm, and surface waters that are not admitted intentionally. See wastewater.

sanitary wastewater — (1) Domestic wastewater with storm and surface water excluded. (2) Wastewater discharging from the sanitary conveniences of dwellings (including apartment houses and hotels), office buildings, industrial plants, or institutions.

sewage — This term is no longer in common use. See wastewater.

sewer — A pipe or conduit that carries wastewater or drainage water.

sewer outfall — The structure through which wastewater is finally discharged.

sewer outlet — The point of final discharge of wastewater or treatment plant effluent.

sewer system — Collectively, all of the property involved in the operation of a sewer utility. It includes land, wastewater lines and appurtenances, pumping stations, treatment works, and general property. Occasionally referred to as a sewerage system.

**storage-grinder-pump (sgp) — An assembly or unit for preparing and pressurizing wastewater from individual homes; a major component of the ASCE Project system (See Section V).

storm sewer — A sewer that carries storm water and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes. Also called storm drain.

suspended solids — Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.

trunk sewer — A sewer that receives many tributary branches and serves a large territory. See main sewer.

wastewater — The spent water of a community. From the standpoint of source, it may be a combination of the liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with any groundwater, surface water, and storm water that may be present. In recent years, the word wastewater has taken precedence over the word sewage.

wastewater facilities — The structures, equipment, and processes required to collect, carry away, and treat domestic and industrial wastes, and dispose of the effluent.

wastewater outfall — The structure through which wastewater is finally discharged.

wastewater outlet — The point of final discharge of wastewater or treatment plant effluent.

(**: Not included in Glossary: Water and Wastewater Control Engineering, ASCE, WPCF, AWWA, APHA, In Press)

APPENDICES

Appendix A — Abstracts of Project Technical Memoranda

Appendix B — Abstracts of Project Subcontractors' Reports

NOTE — Copies of technical memoranda and subcontractors' reports are available at $3.00 per copy from the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, Springfield, Va. 22151. Orders should specify item title and the Clearinghouse identifying number.

Clearinghouse Identifying Numbers

Technical Memoranda	
No. 1	PB 185 995
No. 2	PB 185 996
No. 3	PB 185 997
No. 3A	PB 185 998
No. 4	PB 185 999
No. 5	PB 186 011
No. 6	PB 186 012
No. 7	PB 186 013
No. 8	PB 186 014
No. 9	PB 186 015
No. 10	PB 186 006
No. 11	PB 186 007
No. 12	PB 186 008
No. 13	PB 186 009
No. 14	PB 186 010

Subcontractors' Reports	
Brown & Caldwell	PB 186 001
Greeley & Hansen	PB 186 003
Camp, Dresser & McKee	PB 186 000
General Electric, March, 1967	PB 185 990
General Electric, April, 1968	PB 185 994
General Electric, Dec., 1968	PB 186 004
FMC Corporation	PB 185 991
National Sanitation Foundation	PB 185 992
Johns-Manville	PB 186 005
Univ. of Illinois, March, 1968	PB 185 993
Univ. of Illinois, Nov., 1968	PB 186 002

APPENDIX A

ABSTRACTS OF PROJECT TECHNICAL MEMORANDA

"OUTLINE DESCRIPTION OF ASCE PROJECT ON SEPARATION OF SANITARY SEWAGE FROM COMBINED SYSTEMS OF SEWERAGE"

Technical Memorandum No. 1
February 21, 1966
(Reference 1, Section XVI, "Bibliography")

The general concept of the ASCE Project scheme is to discharge comminuted sanitary sewage from individual buildings and building complexes through relatively small pressure tubing laid in existing building connections and thence into new pressure conduits suspended in existing street sewers. Potential advantages of the scheme are discussed. The ultimate goal of the Project is to develop feasible designs and operations and to put them to test in actual systems. The immediate objective is to examine and evaluate both the feasibility and probable cost. The background of the project is reviewed. Dr. Gordon M. Fair conceived the scheme on which the Project is based. An appendix summarizes the need for separation of combined sewerage systems and the national scope of the problem. (9 pp.)

"SEWAGE FLOW VARIATIONS IN INDIVIDUAL HOMES"

Technical Memorandum No. 2
by L.S. Tucker
February 24, 1967
(Reference 2, Section XVI, "Bibliography")

Winter water demands are assumed to represent sewage flows in the absence of sewage flow data. Two sets of 1-minute interval household water demand data are used: from six homes in Maryland for two weeks, and from two homes in Louisville for four weeks. Maximum and minimum 24-hour and 60-, 15-, and 4-minute demands for each day are given for each home. Frequency distributions of 24-hour and 60-minute flows for each sample are compared with each other and with distributions of total flows from groups of 3 houses and 6 houses. Based on routing of peak flows from nearly five hundred home-days of data through various storage-pump combinations, a pump capacity of 10 GPM and a usable storage capacity of 30 gal. are indicated for initial sizing of household storage-grinder-pump units. Pressure discharge tubing for pressure building services to handle expected flows at reasonable head losses would be 3/4 to 1 1/4 inch I.D. (70 pp.)

"EXPERIENCE WITH GRINDING AND PUMPING OF SEWAGE FROM BUILDINGS"

Technical Memoranda Nos. 3 and 3A
by D.H. Waller
May 1, 1967 and March 1, 1968
(Reference 3, Section XVI, "Bibliography")

In T.M. 3, a typical garbage grinder is described and use of grinders for toilet wastes is reviewed. Two wet process building-waste pulping systems and two machines that combine the functions of grinding and pumping are described. Practice in the use of pumps, piping and backflow valves for sewage in buildings is reviewed. An appendix describes the Liljendahl vacuum sewerage system. (102 pp.)

Results of monitoring the operation of thirty-six comminutor installations that serve individual buildings are reported in T.M. 3A. The monitoring program, which covered periods of up to sixteen months, is described. Descriptions and prior operating histories of the installations are included. Frequency of attention and maintenance is recorded and compared with manufacturers' recommendations. Twenty-five of the machines were inspected at least five times each week. Twenty-four of the installations include sewage pumps following the comminutors with discharge mains 3 to 6 inches in diameter. An appendix contains a summary description of a system developed at Pennsylvania State University for conservation of water in residences by recycling. (47 pp.)

"STUDY OF APPROXIMATE LENGTHS AND SIZES OF COMBINED SEWERS IN MAJOR METROPOLITAN CENTERS"

Technical Memorandum No. 4
by Dasel E. Hallmark and John G. Hendrickson, Jr.
May 1, 1967
(Reference 4, Section XVI, "Bibliography")

A tabulation is given for five major cities of mileage and percentage of combined sewers with heights: greater than 48 inches; equal to or less than 48 inches; and equal to or less than 24 inches. An average of 72 per cent of the sewers are smaller than 24 inches. Heights of 54 inches and larger, classified as walk-through sewers, account for an average of about 15 per cent of the total combined sewer mileage. (9 pp.)

"PRESSURE TUBING FIELD INVESTIGATION"

Technical Memorandum No. 5
by L.S. Tucker
August 15, 1967
(Reference 5, Section XVI, "Bibliography")

Three methods of installing pressure tubing from houses or small buildings, and of connecting the tubing with street pressure conduits, are described and discussed. One would be the installation and connection of pressure tubing and conduit in trenches by traditional water distribution methods. Field trials were conducted to indicate the feasibility of inserting tubing in building sewers. Tubing was pushed through an 86 foot long 4 and 5 inch diameter building lateral, which included three 45° bends, from a specially dug pit at the upstream end into a 4 foot diameter combined sewer. The forward end of the tubing was guided by a special leader device. 3/4, 1, and 1½ inch polyethylene tubing could be pushed. Polybutylene and copper tubes could not be pushed because they buckled or crimped. A Kellems grip and swivel on the end of a rope were used to pull tubing from the combined sewer to the upstream pit. 3/4, 1, and 1¼ inch polyethylene and 3/4 and 1 inch polybutylene could be pulled. 3/4 inch copper tubing could not be pulled because of its stiffness. The third method, tested in the field, combined the insertion of tubing with a street main in trench. (29 pp.)

"HYDRAULICS OF A PRESSURIZED SEWERAGE SYSTEM AND USE OF CENTRIFUGAL PUMPS"

Technical Memorandum No. 6
by L.S. Tucker
November 15, 1967
(Reference 6, Section XVI, "Bibliography")

Hydraulic gradients for high and low flows and the use of pressure control devices for service zones and at the interceptor are illustrated and discussed. For some flat drainage areas sewage pumping would be necessary; a pressure control assembly would be needed immediately upstream and a surge control valve would be used immediately downstream of a lift station. For steep drainage areas, pressure control assemblies would be needed to limit maximum pressures. Centrifugal pump characteristics are discussed and information on thirty-two classes of sewage and solids handling pumps is tabulated. Sewage pump characteristics are such that maximum reasonable limits on discharge rates would be greatly exceeded if variations in total dynamic head were allowed to equal curb pressure variations that are expected in some parts of a pressure sewer system. Ordinary use of centrifugal pumps in these cases would be precluded. A possible modification of building pumping systems with a valve controlled to maintain a constant discharge pressure is discussed together with the use of variable speed drivers. (35 pp.)

"MINIMUM TRANSPORT VELOCITY FOR PRESSURIZED SANITARY SEWERS"

Technical Memorandum No. 7
by M.B. McPherson, L.S. Tucker and M.F. Hobbs
November 16, 1967
(Reference 7, Section XVI, "Bibliography")

Raw sewage, with and without particle-size reduction by comminution, was pumped through 2-in. to 8-in. clear plastic pipe. Extensive observation indicated rather conclusively that the material last to be scoured and first to be deposited was predominantly sand. For all tests, the sewage was salted with ground egg shells but these were always moved at lower mean flow velocities than the sand, which was in low concentrations, viz., 8 to 78 ppm. No discernable difference was noted in the minimum transport velocities for comminuted and uncomminuted sewage, and the difference between minimum scouring velocities and maximum depositing velocities was small. Test results were blended with those from sand transport experiments elsewhere for general representation. Exploratory open channel tests were made with the 8-in. pipe for a firmer correlation with sand tests. Results are presented in terms of dimensionless parameters. Limited tests were made on an 8-in. spiral corrugated pipe. (23 pp.)

"DOMESTIC SEWAGE FLOW CRITERIA FOR EVALUATION OF APPLICATION OF PROJECT SCHEME TO ACTUAL COMBINED SEWER DRAINAGE AREAS"

Technical Memorandum No. 8
by M.B. McPherson
November 17, 1967
(Reference 8, Section XVI, "Bibliography")

Residential sewage flow criteria are developed for use in design of pressurized sanitary sewers for hypothetical applications of the ASCE Project scheme. In a typical combined sewer area, data on domestic water demands is the most that can be expected to be available. On the basis of a study of winter water demand data it is concluded that projection of such observed demands for a service area to the end of the design period is the preferred basis of design. Data for California and the northeastern United States are presented separately. For each region, design curves represent the variation, as a function of the number of dwelling units served, of flows for the minimum 24 hours, for the peak hour of the minimum day, and for the maximum peak hour of any day, expressed as ratios to the annual average rate. (19 pp.)

"PEAK FLOWS OF SEWAGE FROM INDIVIDUAL HOUSES"

Technical Memorandum No. 9
by D.H. Waller
January 1, 1968
(Reference 9, Section XVI, "Bibliography")

Sewage flows and water demands measured at two household observation stations, as well as water and wastewater flows from individual fixtures and appliances is used to estimate upper limits of pump and storage capacities for a storage-grinder-pump unit for individual homes and to examine the relationship between peak rates of sewage flow and corresponding water demand rates. For individual fixtures, combinations of rate, duration and frequency of discharge that will produce maximum hydraulic loading conditions are selected. Single-fixture hydrographs are combined to produce synthetic hydrographs of peak period sewage discharge, from which combinations of storage and pump capacities are derived. Peak sewage flows and simultaneous water demands for a fourteen day period at one house are presented and analysed. (117 pp.)

"AN EXAMINATION OF THE BENEFITS AND DISADVANTAGES WITH RESPECT TO THE DISPOSAL OF SOLID WASTES"

Technical Memorandum No. 10
by D.H. Waller
February 1, 1968
(Reference 10, Section XVI, "Bibliography")

Important considerations in an evaluation of the feasibility and benefits of adapting any sewerage system to solid wastes disposal are: the extra solids load that community refuse could add to a sewage disposal system; velocities required to move solid wastes and the effect of flow variations on sewer velocities; solid wastes separation practices and attitudes toward separation of household refuse; the need for grinding, and considerations involved in the development of a household refuse grinding device; the effects of solid wastes on sewage treatment processes; and costs and benefits involved in evaluation of alternative systems for disposal of sewage and solid wastes. Considerations peculiar to the ASCE Project scheme are: the possibility of adapting building sewage storage-grinder-pump units for handling solid wastes; the need to discharge solid wastes into the system under pressure; reduced clearances in the small pipes of a pressure system; and the possibility of greater solids deposition at low flows. Appendices include information on: composition and characteristics of solid wastes; pertinent solid wastes research and development; and results of research on transport and treatment of solid wastes in sewage disposal systems. (54 pp.)

"CONTROL TECHNIQUES FOR PRESSURIZED SEWERAGE SYSTEMS"

Technical Memorandum No. 11
by James R. Daneker and William H. Frazel
March 4, 1968
(Reference 11, Section XVI, "Bibliography")

Instrumentation and control of a pressurized sewerage system can be attained with current technology, and special designs are foreseen that can approach zero maintenance. A rubber-seated butterfly valve is recommended. A venturi type element or a magnetic meter could be used in flow control. For control of pressure in response to flow changes, a transducer will be required to generate some characterized signal that will be the set point for a pressure controller. The transducer should incorporate a cam that can be cut in the field. "System No. 1" maintains a fixed pressure upstream of the control element by modulation of the valve to correct or reduce any deviation of measured pressure from a selected set point. "System No. 2" modulates the valve to maintain a specific upstream pressure corresponding to every rate of flow measured at the flow element. "System No. 3" would control the start-stop sequence of a booster or lift station centrifugal pump to permit starting without surge and maintain a constant discharge pressure. For a booster station this system would vary pump speed in response to suction pressure. For nearly fool-proof fail-safe control, an all-hydraulic control system is recommended in preference to pneumatic, hydrc-pneumatic, or electronic systems. (27 pp.)

"NON-MECHANICAL CONSIDERATIONS INVOLVED IN IMPLEMENTING PRESSURIZED SEWERAGE SYSTEMS"

Technical Memorandum No. 12
by D.H. Waller
May 31, 1968
(Reference 12, Section XVI, "Bibliography")

Installation of a storage-grinder-pump unit in every home raises questions regarding: allocation of costs of the units; responsibility for malfunction of the units; arrangements for service of the units; and willingness of owners to accept the presence of units in their buildings. Twenty-five householders in Radcliff, Kentucky, whose houses are served by sewage ejector units were interviewed to obtain opinions about features of the units that appeared to represent potential sources of nuisance, inconvenience, or other liabilities. Also interviewed were the superintendent of the utility operating the Radcliff sewerage system, owners of five houses in Louisville, Kentucky, at which sewage sampling stations were located, and three consulting engineering firms who have considered schemes involving the installation of sewage pumping equipment on private properties. Opinions and practices reported reflect the view that sewage pumping equipment placed on private property as part of a public project should be purchased, installed, and serviced at public expense. (27 pp.)

"SPECIAL REQUIREMENTS FOR A FULL SCALE FIELD DEMONSTRATION OF THE ASCE COMBINED SEWER SEPARATION PROJECT SCHEME"

Technical Memorandum No. 13
by D.H. Waller
June 3, 1968
(Reference 13, Section XVI, "Bibliography")

Matters that should be considered in planning a field demonstration of the ASCE Project pressure sewerage scheme are summarized. These include: importance of connecting as many buildings as possible in the demonstration project area; need for protection from overflows of building storage-grinder-pump units; relationship between occurrence of overflows from buildings and given levels of public inspection, detection and control; effectiveness of alarms on SGP units; legal agreements with property owners; importance of complete records of project costs; effectiveness of the project as a pollution control measure; possible benefits of elimination of infiltration from interceptors and treatment plants; detection and clearing of obstructions; use of polymer additives to reduce fluid friction; behavior of unground sewage including anaerobic decomposition; self-cleansing characteristics of flow; rate and extent of deterioration of friction factors; sewage flow variations and their relationship to water demands; handling of interruptions of service; and field tests on installations in walk-through combined sewers. The appendix is an assessment of the physical problems to be overcome in separation of plumbing on private property, with estimates of cost, based on information from officials in seven large cities having combined sewers, and from a consulting engineer and a recent American Public Works Association survey. (84 pp.)

"ROUTING OF FLOWS IN SANITARY SEWERAGE SYSTEMS"

Technical Memorandum No. 14
by L.S. Tucker
July 18, 1969
(Reference 14, Section XVI, "Bibliography")

Water demand data from individual homes, assumed to represent sewage flows, are combined by routing into a 10-home input unit. These input units are then routed through a collection system via a hydrograph superposition procedure. The hypothetical pressure system serves 3,270 dwelling units. The ratio of peak flow to the two-week average flow is 2.7 at the outlet. Similar analyses of portions of the pressure system consisting of 1,000 and 250 dwelling units are made. The ratio of peak to the two-week average for the 1,000 dwelling unit portion of the system is 3.5, and for the 250 dwelling unit portion of the system is 4.0.

A method of analysis based on notes and calculations of Professor H.A. Thomas of Harvard U. involving theoretical moments of frequency distributions is presented. The method is explained by applying it to a simple example of a sewage collection system. The method provides an estimate of peak flows and time of occurrence, and has a potential for examining parameter sensitivity. (39 pp.)

APPENDIX B

ABSTRACTS OF PROJECT SUBCONTRACTORS' REPORTS

"SEPARATION OF COMBINED WASTEWATER AND STORM DRAINAGE SYSTEMS, SAN FRANCISCO STUDY AREA" (TASK 4)

Brown and Caldwell, Consulting Engineers
San Francisco, California
September, 1968
(Reference 16, Section XVI, "Bibliography")

The report is one of three by consultants to study the design, estimate costs and evaluate the feasibility of the hypothetical application of the ASCE Project scheme of pressure sewers for separation in representative combined sewer areas from layouts by the Project staff.

The San Francisco study considered the 323 acre predominantly residential, steeply sloping Laguna Street Sewer Service District, rebuilt since the 1906 fire. The report describes methods of building plumbing separation and indicates two alternative arrangements of pressure sewers, with plans and profiles. Estimates of construction cost of each ($13,000,000 and $13,350,000) are compared with that of a conventional gravity system of separation designed earlier by the City ($8,800,000). Plumbing separation, included in the above, is estimated to cost about $5,400,000 for the gravity method and about $4,400,000 for the pressure method, not including storage-grinder-pump units. (81 pp.)

"COMBINED SEWER SEPARATION PROJECT, REPORT ON MILWAUKEE STUDY AREA" (TASK 4)

Greeley and Hansen, Consulting Engineers
Chicago, Illinois
December, 1968
(Reference 17, Section XVI, "Bibliography")

The report is one of three by consultants to study the design, estimate costs and evaluate the feasibility of the hypothetical application of the ASCE Project scheme of pressure sewers for separation in representative combined sewer areas from layouts by the Project staff.

The Milwaukee study considered the 157-acre mainly dense residential, moderately sloping Prospect Avenue Study Area essentially built prior to 1930 with many buildings dating from before 1900. The report describes methods of building plumbing separation and indicates two alternative arrangements of pressure sewers with plans and a profile. Estimates of construction cost of each ($3,225,000 and $3,260,000) are compared with that of a conventional gravity system of separation designed by the consultant ($2,195,000). Plumbing separation, included in the above, is estimated to cost $912,000 for the gravity alternative and $971,000 for the pressure alternatives, not including storage-grinder-pump units. (84 pp.)

"REPORT ON PRESSURE SEWERAGE SYSTEM, SUMMER STREET SEPARATION STUDY AREA, BOSTON, MASSACHUSETTS" (TASK 4)

Camp, Dresser & McKee, Consulting Engineers
Boston, Massachusetts
September, 1968
(Reference 18, Section XVI, "Bibliography")

The report is one of three by consultants to study the design, estimate costs and evaluate the feasibility of the hypothetical application of the ASCE Project scheme of pressure sewers for separation in representative combined sewer areas from layouts by the Project staff.

The Boston study considered the 53-acre gently sloping, heterogeneous commercial Summer Street Separation Study Area, including many buildings built in the late 1800's. The report describes the separation of building plumbing in detail in a typical three-quarter century old five story and basement commercial building 65-ft. by 145-ft. in plan, and estimates the cost of plumbing separation. Four alternative pressure sewer collection systems are indicated with plans and hydraulic profiles. Some systems included in-line main pumping stations. The least expensive complete pressure system, which did not include a main pumping station, is estimated to cost $6,400,000 compared to the cost of a gravity separation system designed by the consultants, estimated to cost $4,700,000. Both costs include costs of building plumbing separation, $4,000,000 for the pressure system including communitors, wet wells and non-clog pumps, and $2,000,000 for the gravity system. (82 pp.)

"SAMPLING AND ANALYSIS OF WASTEWATER FROM INDIVIDUAL HOMES" (TASK 2)

by R.P. Farrell, J.S. Anderson, and J.L. Setser
General Electric Company
Appliance Park, Louisville, Kentucky
March 24, 1967
(Reference 19, Section XVI, "Bibliography")

The results of the initial phase of operation of two household wastewater observation stations are described. During a three month period household wastewater was sampled for analysis, wastewater flow rates were measured, and the behavior of components when handling wastewater under actual conditions of use was observed. Each station included a garbage grinder for reduction of incoming sewage solids sizes, a float well and level recorder, a pump and pump operation time recorder, a check valve on the pump discharge line, and fifty feet of clear plastic discharge tubing. An extensive program of sampling and analysis was carried out to characterize completely the wastewater from each home. Particulate matter in the wastewater was analyzed over an intensive seven-day period to determine its exact nature in terms of particle size, density and microscopic appearance. Analyses were made of water demand data obtained from measurements at one gallon intervals at each house telemetered to recording equipment. A set of fixture tests, during which fixtures were discharged singly and in combinations in preplanned sequences, was run at both stations to obtain information on water and sewage flow patterns for fixtures. (79 pp.)

"LONG-TERM OPERATION OF WASTEWATER OBSERVATION STATIONS" (TASK 2)

by R.P. Farrell
General Electric Company
R. and D. Center, Schenectady, N.Y.
April 24, 1968
(Reference 20, Section XVI, "Bibliography")

In the terminal phase of operation of two household wastewater observation stations (see preceding abstract), the stations were operated for seven months during which the principal objective was collection of usage experience. The two garbage grinders were never a source of difficulty. The 3/4 inch check valves regularly trapped fibrous or stringy materials. A significant increase in head loss in the 3/4 inch discharge tubing in the last month of operation at one station is attributed to a thick coating of anaerobic slime on the interior walls, attributed to low inflow rates and extended periods of disuse. The 1-inch tubing at the other station was essentially clean throughout the tests. Results of fixture flow tests, and information on overflows from the station wet-wells, was obtained to supplement results of the earlier studies. (48 pp.)

"ADVANCED DEVELOPMENT OF HOUSEHOLD PUMP-STORAGE-GRINDER UNIT" (TASK 6)

by R.P. Farrell
General Electric Company
R. and D. Center, Schenectady, N.Y.
December, 1968
(Reference 21, Section XVI, "Bibliography")

This report describes the development, by the General Electric Company for the ASCE Project, of a 150-pound household SGP unit comprising a domestic sewage grinder and progressing-cavity pump driven by a 1-h.p., 1725-r.p.m. motor, and mounted on a 58-gallon receiver tank, meeting criteria established by the Project investigation. The unit is capable of discharging through a backflow valve and 1¼-in. outlet at 15-gpm at atmospheric pressure and 11-gpm at 35 psig pressure. The estimated cost of the unit without tank is $343, and estimated total installed costs are $548 for new work and $648 where cutting and patching are involved. Cost of energy for operation is about $2 per year. (74 pp.)

"RELATIONSHIP OF SEWAGE CHARACTERISTICS TO CARRYING VELOCITY FOR PRESSURE SEWERS" (TASK 5)

by M.F. Hobbs
Central Engineering Laboratories
FMC Corporation, Santa Clara, California
August, 1967
(Reference 22, Section XVI, "Bibliography")

Minimum carrying velocities for solid phase matter in smooth plastic 2", 3", 4", 6", and 8" pressure pipes were measured using comminuted and uncomminuted raw sewage. The minimum velocity for scouring and the maximum velocity for depositing were essentially the same. Velocities appeared to be independent of: the concentration magnitudes of suspended solids, fixed suspended solids, sand concentration, and the size distribution of suspended matter and sand for the sewages studied. Velocities appeared to be dependent on the fixed solids content. Egg shells that had been passed through a garbage grinder were carried at lower flow rates than required for moving the bottom sediments. Carrying velocities were investigated in an 8" spiral pressure pipe but the results obtained were very erratic. Tests were also made on the 8" plain plastic pipe with open channel flow. All data acquired are reported. (96 pp.)

"REPORT TO ASCE COMBINED SEWER SEPARATION PROJECT ON FWPCA CONTRACT NO. 14-12-29" (TASKS 7 AND 9)

by Robert N. Bowen and John G. Havens
National Sanitation Foundation, Ann Arbor, Mich.
December, 1967
(Reference 23, Section XVI, "Bibliography")

Assistance was provided in connection with special field trial installations of flexible tubing inserted in building sewers. Materials were proposed for pushing or pulling through a building sewer and a methodology and necessary attachments and tools were recommended. Polyethylene and polybutylene tubing are recommended for use inside building sewers and copper tubing for use in open trenches. A saddle type of connection is recommended for connection of pressure tubing to street pressure conduits. Cast iron, PVC, asbestos cement, or ductile iron are recommended for pressure conduits. Experience with plowing of pressure pipe is reviewed. Reference is made to standard practice for trench installations, street crossings and thrust blocking. Two methods of cleaning house pressure tubing are proposed. Six possible layouts of pressure conduits are discussed in terms of operation and maintenance. All six arrangements provide for routine rerouting of flow by exploiting a dual conduit configuration. (55 pp.)

"DEVELOP AND FIELD TEST METHOD OF INSTALLING PRESSURE CONDUITS IN COMBINED SEWERS" (TASK 7)

by H.J. Kazienko
Research and Engineering Center
Johns-Manville Products Corporation, Manville, N.J.
December 30, 1968
(Reference 24, Section XVI, "Bibliography")

This report describes the development and testing in the laboratory of polyester molded hangers cemented to the sewer pipe crown. Polyester hanger material formulations, epoxy cement, and hanger dimensions are specified, and methods of installation given in detail. Test of the hanger to failure in the laboratory showed fracture in tension through the conduit ring, leaving the upper part bonded to the concrete sewer crown. The field installation of 100-ft. of 3-in. diameter PVC pipe filled with water was made in a 7-ft. sewer in Evanstan, Ill., in cooperation with the Metropolitan Sanitary District of Greater Chicago. The installation was sound and unaffected when removed after 4½ months. (38 pp.)

"TURBULENT FRICTION IN ECCENTRIC ANNULAR CONDUITS" (TASK 12)

by James M. Robertson
Department of Theoretical and Applied Mechanics
Report No. 310
University of Illinois, Urbana, Ill.
March, 1968
(Reference 25, Section XVI, "Bibliography")

Following a general review of the analytical and experimental information on the friction loss encountered by fluids flowing in annular pipes, with particular regard to the influence of eccentricity of the inner member, experiments are described on an evaluation of the friction of water in a steel annular pipe of diameter ratios 5.8 and 3.2 in the Reynolds number range of 10^5 to 10^6. It is found that on a discharge basis, for the same head loss in a given length, with the diameter ratio of 5.8 the flow capacity of the pipe line is decreased 12.7% in the concentric situation but only 4.5% with full eccentricity. The latter decrease is not greatly different from the 3% reduction in area due to the inserted smaller pipe. An analysis is included showing that for the simple insert at full eccentricity the near-full-flow capacity of a sewer is little affected. The effects of hangers such as might be employed to support inserts in sewers is found to have an appreciable effect on the flow capacity of a full-flowing sewer. (63 pp.)

"ANALYTICAL STUDIES OF TURBULENT FRICTION IN ANNULAR CONDUITS, EFFECT OF INSERTED PIPE ON FLOW CAPACITY OF SEWERS" (TASK 12)

by Alan R. Nelson and J.M. Robertson
Department of Theoretical and Applied Mechanics
Report No. 321
University of Illinois, Urbana, Ill.
November, 1968
(Reference 26, Section XVI, "Bibliography")

An analytical solution for fully developed turbulent flow in an annular conduit is presented, performed with the aid of a digital computer. To account for the observed divergence of the velocity traverses of recent investigations with increasing ratio of radius of inside wall of outside pipe to radius of outside of inserted pipe, a modified wall law-core law velocity formulation is adopted. The effect of variations in radius ratio, eccentricity, and roughness upon the location of maximum velocity, velocity distribution, and friction are discussed. The radius of maximum velocity is found to be nearer the wall of the inserted pipe for smooth annuli and is independent of Reynolds number for values greater than 40,000. Friction decreases with increased eccentricity but is considerably less affected by changes in the radius ratio. Variations in wall roughness cause the greatest alteration in the flow occurrences in annular conduits. Using the modified two-law velocity distribution, a new prediction of friction is given for the limiting case of radius ratio approaching unity. Even though equivalent magnitudes were not achieved for experimental and analytical results, the trends are similar. (81 pp.)